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NORTH CANADIAN RIVER INVESTIGATION. A STUDY OF THE POSSIBLE CHANGES IN THE QUALITY OF THE WATER OF THE NORTH CANADIAN RIVER FOR WATER SUPPLY AND OTHER PURPOSES DUE TO PROPOSED FLOOD CONTROL RESERVOIRS, AND THE QUANTITY OF DILUTING WATER REQUIRED FOR POLLUTION ABATEMENT BELOW OKLAHOMA CITY

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Public Health Service
Cincinnati, Ohio

1939

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U. S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
OHIO RIVER POLLUTION SURVEY
ROOM 1309 ENQUIRER BLDG.,
CINCINNATI, OHIO

NORTH CANADIAN RIVER INVESTIGATION

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BY

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REPORT PREPARED BY THE U. S. PUBLIC HEALTH SERVICE AT THE REQUEST OF THE U. S. ENGINEER DEPARTMENT AND THE OKLAHOMA STATE HEALTH DEPARTMENT.

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Introduction

The special investigation of the North Canadian River, reported herein, was directed by the Surgeon General of the U. S. Public Health Service, under date of August 16, 1939, in response to requests from the U. S. Engineer Department and the Oklahoma State Health Department dated July 24, 1939 and May 16, 1939, respectively.

Expenditures for the investigation were made from funds allocated to the Public Health Service by the Chief of Engineers for the Ohio River Pollution Survey, reimbursement, in the manner prescribed by Federal Statutes, to be made from funds allotted to the District Engineer, U. S. Engineer Office, Tulsa, Oklahoma, for studies of flood control on the North Canadian River.

Preliminary conferences to outline the various phases of the investigation and methods of procedure were held at Tulsa, Oklahoma, with the District Engineer, U. S. Engineer Office, on September 2, 1939, and with the State Health Commissioner and the Director of the Bureau of Sanitary Engineering, Oklahoma State Health Department, Oklahoma City, September 3, 1939.

The scope of the survey was confined to a study of the need, the value, and the effect of conservation storage, should a proposed channel reservoir in the North Canadian River basin be so constructed as to operate in the interest of pollution abatement as well as for other purposes for which designed.

The specific problems covered by the investigation, as propounded by the U. S. Engineer Department, were to determine:

A. Storage capacities that should be provided in reservoirs on the North Canadian River for correction of stream pollution conditions, and the desirable rate of release for that purpose.

B. Estimated monetary value, on an acre-foot basis, of water stored for stream pollution abatement.

C. The effect that the storage of waters in reservoirs on the North Canadian River may have on present methods of water softening and purification at Oklahoma City.

This special investigation has been under the administrative supervision of the Office of Stream Sanitation, U. S. Public Health Service, Cincinnati, Ohio, with Associate Public Health Engineer M. D. Hollis, who has prepared the report of the study, in immediate charge of the field work with temporary headquarters at Oklahoma City, Oklahoma.

Field personnel included two junior engineer recorders from the U. S. Engineer Office at Tulsa, Oklahoma, and the part-time services of an Assistant Sanitary Engineer and a Chemist from the staff of the Oklahoma State Health Department. Field headquarters for the investigation were established in space provided by the Oklahoma State Health Department.

Field investigations were made during the 8-week period September 11 - November 8, 1939. Field contacts for the collection of factual data were made in collaboration with the Oklahoma State Health Department. Factual data on water supply, sewage and industrial waste disposal were obtained by field visits to all municipalities and industries in the basin. Recording gage measurements were made of significant sewage flows reaching the North Canadian River from the affected area. The laboratory of the Oklahoma State Health Department was used for biochemical oxygen demand determinations of samples of raw waste from the principal sources of pollution.

During the investigation there was no flow in the North Canadian River except that produced by sewage effluents immediately below outfalls, and this condition prevented such limited laboratory observations as might have been made of general stream behavior.

All hydrometric data used in analyzing the problems were secured from the District Engineer, U. S. Engineer Office at Tulsa, Oklahoma.

Splendid cooperation was secured from federal agencies and various State and municipal legislative bodies contacted during the process of assembling basic data. Special acknowl-

edgment is due the U. S. Engineer Office at Tulsa, Oklahoma, and the Oklahoma State Health Department, through whose efforts the investigation was made possible; to the city officials at Oklahoma City, from whose records was obtained much valuable information relating to river water quality; to the Oklahoma Planning and Resources Board for data regarding oil field waste pollution; to the U. S. Weather Bureau Station at Oklahoma City; the State Geologist at Oklahoma University; the State Fish and Game Department; the Petroleum Experiment Station at Bartlesville, Oklahoma; and the State Agricultural College for making file data available for reference.

General Summary

The investigation of the North Canadian River, as covered by this report, was primarily to determine necessary conservation storage for pollution abatement, required minimum seasonal flows, the tangible monetary benefits accruing from such stream regulation, and the effects of the channel impoundment on the use of the river as a source of public water supply at Oklahoma City. The report presents available data relating to these problems and attempts to analyze these data from the standpoint of the specific questions propounded. Section One includes general data pertinent to the basin as a whole. Section Two covers the detail problem analyses.

In regards the specific questions propounded, there follows, in outline form, a general summary of conclusions which appear warranted from the detail analysis of available data:

(1) Stream flow of the North Canadian River is extremely erratic, being characterized by flash floods of damaging proportions and, conversely, by long periods of near zero flow.

(2) At low flows, pollution of the North Canadian River, by municipal and industrial wastes, reaches significant proportions at and below Oklahoma City.

(3) Pollution abatement by stream regulation from conservation storage should be combined with reasonable treatment of organic wastes prior to discharge.

(4) With 40,000 acre-foot storage capacity at Canton, regulated seasonal discharges would provide necessary minimum dilutions for downstream organic waste, provided the daily biochemical oxygen demand (B.O.D.) from Oklahoma City does not exceed 12,000 pounds as measured at 20-day, 20°C. (equivalent 90% reduction in B.O.D. of present waste). Minimum treatment of waste from other riparian communities is recommended as equivalent to 85% reduction of first stage B.O.D.

(5) Neglecting inflow below the reservoir, the required minimum seasonal flows at Canton are computed to be as follows:

June	- September	160 cfs
October	- November	50 cfs
December	- February	25 cfs
March	- May	50 cfs
Weighted Average		81 cfs

(6) It is infeasible to provide minimum flows sufficient properly to dilute brine waste in the quantities produced from oil fields at and below Oklahoma City.

(7) The tangible monetary value of waters stored for organic pollution abatement is computed to be approximately $38. per acre-foot. This figure is derived from the capitalized annual costs for supplemental treatment, should such be substituted for stream regulation. Intangible values should materially increase this figure.

(8) The alkalinity of waters in the North Canadian River varies, averaging from about 180 to 200 ppm for flows below 100 cfs, and about 120 to 150 ppm for flows exceeding 100 cfs.

(9) Oklahoma City proposes to continue using the North Canadian River as a source of water supply by constructing a 75,000 acre-foot off-channel reservoir near the city, which reservoir includes facilities for selective impounding, using a diversion canal of 1500 cfs capacity.

(10) With no upstream reservoirs, Oklahoma City could select, for storage, sufficient waters in the average alkalinity range of 120 to 140 parts per million.

(11) Should the proposed Canton reservoir be operated with 40,000 acre-foot storage capacity for stream regulation, Oklahoma City could select, for storage, sufficient waters in the average alkalinity range of 130 to 150 parts per million.

(12) On a basis of averages the removal of the computed increase in hardness, as calcium bicarbonate, would add about 50 cents per million gallons to treatment cost. Present treatment methods at Oklahoma City do not include removal of non-carbonate hardness.

(13) Increases in alkalinity that might result from permanent pools behind flood control reservoirs, other than Canton are not considered, inasmuch as such effect would occur irrespective of conservation storage at Canton.

(14) Insufficient data exist upon which to base conclusions as to the effect biological development in the Canton reservoir may have on water treatment problems at Oklahoma City. However, if conservation storage at Canton is limited to 40,000 acre-feet, it is doubtful if the diluted water from

the Canton storage would exert much influence on the biological development in the Oklahoma City reservoir.

(15) Interference could be minimized if selectivity of waters for off-channel impoundment at Oklahoma City is practiced in close cooperation with officials controlling the operation of upstream reservoirs.

(16) Conservation storage at Canton would have no detrimental effect on the bacterial quality of waters reaching Oklahoma City.

(17) According to the Oklahoma State Health Department, conservation storage at Canton would create no significant malaria control problems in the area.

SECTION ONE

THE NORTH CANADIAN RIVER BASIN

A - Physical Characteristics.

The North Canadian River Basin, located geographically in the South Central United States, is approximately 540 miles long and drains portions of Oklahoma, Texas and New Mexico. The North Canadian River, 843 miles in length, rises in the high plateau regions of New Mexico and flows easterly 68 miles through New Mexico, thence continuing easterly approximately 250 miles across the Oklahoma-Texas Panhandle, thence southeasterly about 525 miles to its confluence with the South Canadian River.

The watershed outline of the North Canadian River and principal tributaries is shown in Fig. 1. The headwater reaches of the unique-shaped basin resembles a tongue penetrating some 50 miles into New Mexico. The basin widens to approximately 60 miles in the Oklahoma-Texas Panhandle, thence narrowing sharply east of the 100th meridian (mile 537), to form the 200-mile neck-shaped central section which averages 10 miles in width. At its eastern extremity the basin expands into a leaflike shape 60 by 100 miles. The total drainage area of the North Canadian River is approximately 16,850 square miles, of which 11,470 square miles, or 68%, lies within the State of Oklahoma; 4,520 square miles, representing 27%, in the State of Texas; and 860 square miles, or about 5%, in New Mexico. The river valley lies at elevations of 100 to 200 feet above the adjacent valleys of the South Canadian River on the south, and the Cimarron River on the north.

The North Canadian River in its 843-mile course falls 6,000 feet or an average of 7.5 feet per mile. It is approximately 6,500 feet above mean sea level at its source and 500 feet at the mouth. Through the panhandle stretch to the 100th meridian (mile 537), the river gradient averages 17.7 feet, uniformly decreasing to 2.5 feet per mile for the lower 300 miles of its course. The comparatively uniform channel west of the 98th meridian (mile 310) is wide and shallow, while to the east it narrows and deepens. Throughout its course the river occupies a bed of sand of variable depth. The flood valley varies from 1 to 4 miles in width. Excepting the lower third of the basin, east of the 98th meridian (mile 310), the present river channel flows very near the northern watershed divide. Practically all drainage to the river is from the south.

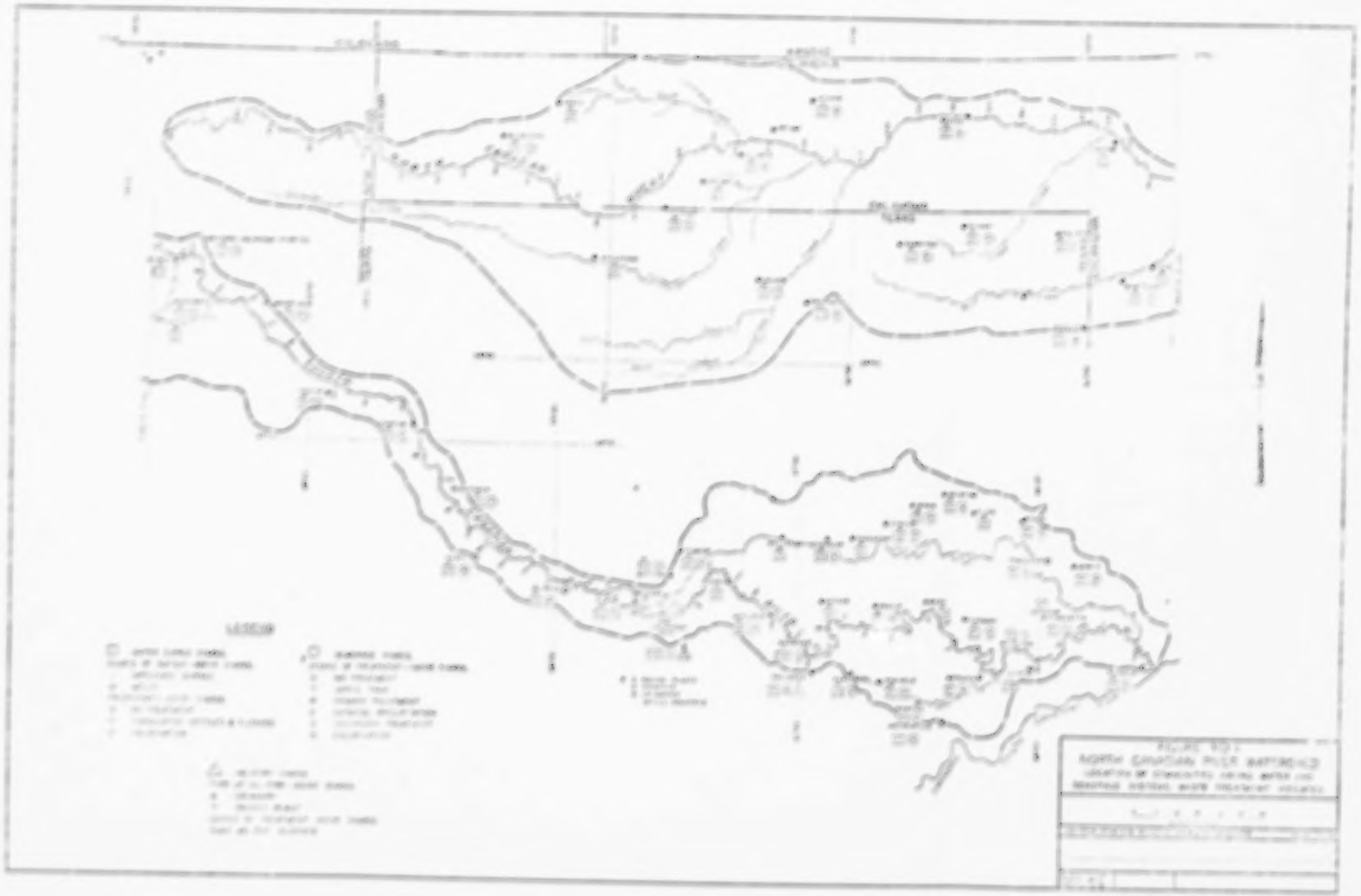
Tributaries: In the order of their distance from the mouth, significant tributaries of the North Canadian River are as follows:

Tributary	River Mile No.	Drainage Area	Location	Drainage From
Deep Fork River	18	2,540	East 96th Meridian	North
Wewoka Creek	82	420	East 96th Meridian	South
Persimmon Creek	443	200	West 98th Meridian	South
Wolf Creek	488	1,680	West 98th Meridian	South
Paladuro Creek	618	1,660	West 99th Meridian	South
Coldwater Creek	688	1,870	West 98th Meridian	South

Topography and Geology: The topography of the North Canadian Basin varies from high rolling plateau regions of New Mexico to gentle sloping plains, flanked by table-lands, in the Texas-Oklahoma Panhandle. The terrain grows rough and hilly as it progresses across Oklahoma proper. In the panhandle section, the reaches north of the river are formed by sand dunes and table-lands, the latter disappearing in the vicinity of the 100th meridian, but the sand dunes continue past the 98th meridian (mile 310) to merge into high rolling country extending to the mouth. Terrain south of the river channel consists of high rolling hills extending from the 101st meridian to the mouth.

Throughout its course, the North Canadian River flows through alluvium of varying depths. West of the 101st meridian the valley cuts into consolidated late tertiary deposits. Between the 101st and 98th meridians the south bank consists principally of Permian Redbeds, of which many units are gypsiferous. The north bank for this stretch is mainly Ogallala formations of calcareous sands, gravels and caliche. East of the 98th meridian the valley is cut into silty shales and sandstones of the Permian Redbeds, changing in the lower reaches to conglomerates of shales, limestones and sandstones.

Population: From Federal Census Statistics the total population of the North Canadian River basin, as of 1930, was 579,120, of which slightly over 300,000, or about 53%, resided in urban communities. The present population of the North Canadian watershed is estimated to be approximately 660,000, with rural-urban ratio holding near that of 1930.



Urban and rural population distribution by States in 1930 was as follows:

	Population of North Canadian River in:			
	Oklahoma	Texas	New Mexico	Basin
Urban	293,953	2,750	3,677	300,410
Rural	263,500	12,455	2,755	278,710
Total	557,453	15,235	6,432	579,120
% of Total	96.2	2.6	1.2	100

West of the 101st meridian the North Canadian basin is sparsely settled while eastward the population density increases, being reasonably uniform to the 98th meridian. The lower reaches of the watershed are thickly settled with greatest population density in Oklahoma and Seminole Counties. The total population of the basin above Oklahoma County (mile 280) in 1930 was about 105,000, while below that point slightly over 452,000 resided.

Of 21 incorporated communities in the basin, 16 are in the urban classification (1930 census) of which Oklahoma City, population 185,389 in 1930, is the largest.

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B - Hydrology

Precipitation: The mean annual precipitation over the North Canadian River Basin averaged 22 inches for the 24-year period 1915-1938, inclusive, varying from around 19 inches in the semi-arid western half of the basin, to about 40 inches in the eastern portion. Extremely wide ranges of annual values for average precipitation in the basin are noted over the period of record, the minimum beung 16.9 inches in 1933 and the maximum 34 inches in 1923.

Records of precipitation are available from 17 U. S. Weather Bureau stations on the watershed, at which observations have been made for from 20 to 49 years. Of these stations, 8 are located in the upper regions of the basin west of the 99th meridian (mile 426). Records of all stations are summarized in Tables 1 and 2 to present the average monthly precipitation together with annual averages and extremes.

Climate: The climate of the North Canadian Basin is temperate and continental, having moderately cold winters and warm summers. Prevailing winds are south to southwest. Mean annual basin temperature is 60°F, with 77°F and 40°F as mean summer and winter temperatures respectively. Temperatures in the 100°F range are common in summer months, with winter minimums seldom below 10°F.

Relative humidities in the basin are generally low, which condition accelerates evaporation over exposed water surfaces. Average humidities, recorded at Oklahoma City, in per cent, by months, are summarized in Table 3.

Table 3. Average Relative Humidity, in Per Cent, for Oklahoma City, as Recorded by U. S. Weather Bureau.

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
7 AM	81.1	79.2	76.3	77.1	88.6	81.7	80.4	81.4	81.9	79.4	78.0	80.6	80.0
12:30 PM	60.9	55.1	48.2	49.4	56.3	52.8	46.0	45.2	50.9	53.2	55.8	59.5	52.8
7 PM	66.6	59.9	53.0	52.3	59.7	56.9	52.5	52.1	56.5	58.6	61.9	66.7	58.0

Yrs. of Record: 7 AM - 1891-1920; 12:30 PM - 1918-1938; 7 PM - 1891-1936.

Evaporation: Average monthly evaporation rates for use in the proposed Canton Reservoir (mile 394), were compiled by the U. S. Engineer Office, at Tulsa, Oklahoma, based on evaporation data collected by the U. S. Department of Agriculture at Woodward, Oklahoma, and the U. S. Engineer Department at Conchas Dam, New Mexico. These evaporation rates, in inches, by months, both as actually measured from standard evaporation pan and as computed for free water surface, using a pan factor of 0.9, are indicated in the following tabulation.

Table 4. Evaporation Rate for Canton Reservoir, in Inches, by Months, for Standard Evaporation Pan and Free Water Surface (Pan data from U. S. Engineer Office, Tulsa, Oklahoma)

Month	Evaporation Rate in Inches		Month	Evaporation Rate in Inches	
	Evaporation Pan	Free Water Surface		Evaporation Pan	Free Water Surface
January	2.77	2.493	July	11.043	9.939
February	3.22	2.898	August	9.929	8.936
March	5.65	5.085	September	7.426	6.683
April	6.342	5.708	October	5.10	4.590
May	7.333	6.600	November	3.41	3.069
June	9.512	8.561	December	2.20	1.980
			Total	73.94	66.542

Table 1 - Average Monthly Precipitation, in Inches, on the North Canadian River Watershed at Individual U. S. Weather Bureau Stations.

Stations	River Mileage	Yrs. Rec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Des Moines, N.M.	N 800	18	0.34	0.68	0.98	2.20	3.12	1.80	3.10	3.59	2.00	1.04	0.74	0.46	19.07
Clayton N.M.	N 590CC150	29	0.22	0.50	0.81	1.70	2.44	1.92	2.77	2.24	1.65	1.26	0.72	0.42	16.65
Perryton, Texas	N 470WC95	23	0.24	1.10	1.17	1.97	2.94	4.05	2.08	2.79	2.11	1.49	1.42	0.66	22.12
Boise City, Okla.	N 700	31	0.19	0.39	0.95	1.01	3.11	2.26	2.01	2.48	1.69	1.65	0.88	0.43	16.05
Goodwell, Okla.	N 617 - 15	29	0.30	0.53	0.76	1.53	2.54	2.37	2.66	2.31	1.84	1.32	0.74	0.52	17.42
Hooker, Okla.	N 600	33	0.24	0.76	0.64	1.66	2.78	2.47	2.68	2.02	1.96	1.76	0.74	0.51	18.22
Beaver, Okla.	N 544	42	0.41	0.90	1.02	1.91	2.65	2.92	2.40	2.29	2.18	1.50	1.08	0.79	20.05
Woodward, Okla.	N 488	86	0.60	1.08	1.43	2.49	3.51	3.59	2.93	2.68	2.80	2.22	1.67	0.88	25.88
Mutual, Okla.	N 831	32	0.54	0.74	1.30	2.66	3.20	3.32	2.20	3.44	2.99	2.16	1.50	0.92	23.86
Geary, Okla.	N 349	27	1.00	1.24	1.83	3.19	4.72	4.02	2.96	2.59	2.96	2.52	1.82	1.38	30.23
Fort Reno, Okla.	N 323	47	1.02	1.21	2.25	3.75	4.73	3.86	2.58	2.68	3.10	2.61	1.85	1.45	31.09
Okla. City, Okla.	N 265	48	1.19	1.11	1.96	3.29	4.88	3.67	2.86	2.89	3.05	2.96	1.97	1.50	31.15
Meeker, Okla.	N 16DF169	45	1.73	1.38	2.62	3.69	5.49	4.21	2.53	3.20	3.24	3.58	2.34	1.79	35.75
Okemah, Okla.	N 16DF105	26	1.96	1.50	2.70	4.07	5.15	3.60	2.70	2.88	3.57	4.02	2.61	1.91	36.67
Shawnee, Okla.	N 195	37	1.56	1.48	2.52	3.71	5.15	4.32	2.76	2.90	3.23	3.54	2.18	1.68	34.94
Holdenville, Okla.	N 80WC33	37	2.35	1.74	2.62	3.88	5.54	3.94	3.02	3.06	3.82	3.56	2.43	2.19	38.09
Eufaula, Okla.	N 4	26	2.53	2.07	2.92	4.31	5.46	3.74	3.20	3.43	3.32	3.88	2.62	2.48	39.86

Table 2 - Maximum, Minimum, and Average Precipitation, in Inches, on the North Canadian River Watershed at Individual U.S. Weather Bureau Stations, above Canton, Oklahoma.

Stations	Maximum		Minimum		Mean
	Year	Precipitation	Year	Precipitation	
Des Moines, N. M.	1923	30.53	1924	9.82	19.07
Clayton, N. M.	1919	27.01	1936	5.54	16.65
Perryton, Texas	1915	34.11	1910	10.27	22.12
Boise City, Okla.	1919	38.97	1934	8.62	16.05
Goodwell, Okla.	1915	26.75	1936	9.69	17.42
Hooker, Okla.	1915	20.59	1910	9.30	18.22
Beaver, Okla.	1923	32.78	1933	10.03	20.05
Woodward, Okla.	1923	45.74	1910	14.01	25.88

Run-off: The vast area of table-lands and sand dunes in the Oklahoma Panhandle contributes very little direct runoff, and tends to impede, by valley storage and bed absorption, such flood flows as originate in the New Mexico headwaters. Throughout most of the panhandle region there is no appreciable direct runoff from the extensive sand dunes north of the river channel. South of the river, runoff conditions are more favorable, especially in the Wolf Creek basin. Rapid run-off occurs in the narrow neck of the watershed to the mouth except for sand dune areas north of the river channel. The normal runoff factor above Canton, Oklahoma (Drainage 11640 square miles), for rains of about one inch, is approximately 2%.

Stream Flows: Stream flows in the North Canadian River are extremely erratic. Peak flows exceeding 100,000 cubic feet per second have been estimated by the U. S. Engineer Department*. Contrawise, long periods of near zero flow are not uncommon. Although several stream gaging stations have been established and operated on the North Canadian River and its tributaries since 1899, their records are short and fragmentary. Tabulated monthly flows at Guymon, Beaver, Canton, and Oklahoma City for 20 or more years, as estimated by the U. S. Engineer Office, Tulsa, Oklahoma, are presented in Appendix "A".

C - Economics

West of Oklahoma City, agriculture is the primary development. Oil production and mining combine with agricultural activity in the eastern reaches. Oklahoma City, the state capitol and largest city in Oklahoma, is located in the midst of a rich oil field and is the key industrial and commercial center of an extensive farming and oil section.

Excepting the sand dune areas north of the river, the North Canadian Valley is, in general, quite fertile. Sand loams are found in the panhandle area, with clayey loams and admixtures of both types in the central and eastern portions. West of the 99th meridian wheat, forage crops, stock raising, and dairying represent principal land uses. In the central and eastern areas farming is more diversified, with wheat, corn, cotton, sorghums, and alfalfa as predominating crops. Dry farming methods are generally used with irrigation limited to about 1,200 acres using 1,800 acre-feet of water

* *North Canadian River, New Mexico, Texas and Oklahoma, House Document 569, 75th Congress, 3rd Session.*

annually of which 600 acre-feet are from surface streams. From Oklahoma City east, oil, natural gas, and allied products are extensively produced.

The few industries in the central region of the basin are essentially those for local processing of agricultural products. Flour mills, local abattoirs, and creameries predominate. Little or no industrial development exists in the western panhandle section.

D - Water Supply and Sewerage

Factual data relative to municipal and industrial water supply and sewerage were secured by field visits to the respective communities and industries. For the area from Woodward, Oklahoma (mile 468) to Shawnee, Oklahoma (mile 197), these data were supplemented by a few laboratory determinations (see Section Two). Excluding oil field, industries in the basin are, in general, located in or adjacent to municipalities and use municipal water and sewerage facilities. In all cases, except for oil field waste, the industrial and municipal figures are combined.

Water Supply: In the North Canadian River Basin public water supply systems serve 58 communities, representing a combined population of about 388,000. For a source of supply 45 communities, representing a population of 87,450, use ground water, and 13 communities, representing a population of 300,550, use surface sources. Ground water troubles in both quantity and quality are experienced in many communities.

Sewerage: Public sewerage systems are available in 43 communities in the North Canadian Basin. These systems serve a combined population of 271,930, of which 222,200, or about 82% reside in the lower portion of the basin from Oklahoma City to the mouth. Principal foci of organic pollution reaching the main stem are located between El Reno (mile 307) and Shawnee (mile 197). Detailed data on these sources are included in tabulations and discussions in Section Two.

Table 5 presents in summary form salient water supply, sewerage, and sewage treatment data, by stream sections, for the North Canadian River watershed. These data are symbolized in Fig. 1.

E - Pollution due to Industrial Wastes

Pollution of the North Canadian River by organic and chemical wastes from industries is of significance in the lower reaches of the watershed. Organic wastes, heaviest at Metropolitan Oklahoma City, are principally from packing plants, creameries, breweries and abattoirs, while chemical pollution is due almost entirely to oil field brine.

Oil field brine reaches the stream from Oklahoma City to the mouth. This reach includes the present most productive wells of the Mid-Continent Oil Fields. Estimates from the Oklahoma Planning and Resources Board, the legal oil field pollution control agency in Oklahoma, show a daily production of 87,500 barrels (oil barrel equals 42 U. S. Gallons) of oil from 1,980 producing wells in the basin.

The fertile river valleys below Oklahoma City and along the Deep Fork River are used for agricultural crops and extensive pecan groves. According to the Planning and Resources Board, excessive brine pollution adversely affects normal land uses in the valleys. Although existing oil fields in the North Canadian Basin are located only in or below Oklahoma City, geological reports do not definitely preclude potential developments in the central and western regions.

Present brine pollution control methods in Oklahoma concentrate on new developments, with abatement measures including treatment, where necessary, and return of brine to producing strata. This appears to be the only positive method of eliminating detrimental effects of mineralized water on water supplies, vegetation, aquatic life and other normal stream uses. Due to quantities produced the evaporation pond method is not successful. Impounding with controlled diversion to surface streams is objectionable because of long periods of low flows.

F - Water Development Plan

At present the contemplated water development program for the North Canadian River comprises the Canton multiple-use reservoir in conjunction with flood control reservoirs at Fort Supply on Wolf Creek, and Optima farther upstream. Such project reservoirs will materially reduce

flood stages in the lower valley and provide conservation storage. Channel improvement for flood protection, on Deep Fork, together with numerous small multiple-use tributary reservoirs, have been constructed by local interests.

According to the U. S. Engineer Department, hydroelectric developments in the basin appear infeasible, as does navigation.

The proposed water development plan for the basin would be beneficial from a public health standpoint. The augmenting of low stream flows would reduce organic pollution and bacterial concentrations below sewer outfalls. Other public health hazards associated with polluted streams would be eliminated or materially reduced. According to the Oklahoma State Board of Health, the proposed conservation works would create no significant malaria control problems, in this particular area.

Table 5 - Summary, by Stream Sections, of Salient Water Supply, Sewerage, and Sewage Treatment Data for the North Canadian River Watershed.

	Main stem Mouth to Okla.City	Deep Fork River	Wewoka Creek	Main stem Bethany-Woodward	Wolf Creek	Paladuro Creek	Coldwater Creek	Above Woodward-Main stem	Total
River Mileage	0-270	15	82	270-465	488	612	623	466-843	0-843
Water Supply									
Communities served	12	14	5	9	4	2	2	10	58
Supply:									
Ground Water	7	9	2	9	4	2	2	10	45
Surface Water	5	5	3	0	0	0	0	0	13
Population served:									
Ground Water	5000	26350	10000	26750	3870	1446	1980	12045	87441
Surface Water	256100	28250	16200	0	0	0	0	0	300550
Sewerage									
Communities served	8	10	5	9	2	2	0	7	43
Sewered population	175600	46600	18500	20800	3570	1446	0	5415	271931
Treatment Plants -									
Primary	2	2	1	3	2	2	0	3	15
Secondary	3	7	4	5	0	0	0	4	23
Pop. Equivalent[e]	520000	130000	20000	25000	4000	2000	0	6000	707000

[e] *Computed using .167 lbs. 5-day B.O.D. per capita per day.*

SECTION TWO

Specific Problems Propounded by

The U. S. Engineer Department

As originally outlined by the U. S. Engineer Department, the U. S. Public Health Service investigation was to include analysis of six specific problems relating to the water development plan for the North Canadian River Basin. Three of the problems were contingent on Oklahoma City securing its water supply from the proposed multiple use reservoir near Canton, Oklahoma. Subsequent to a public hearing at Oklahoma City, conducted by the U. S. Engineer Department on November 7 and 8, 1939, the District Engineer, U. S. Engineer Office at Tulsa, Oklahoma, eliminated these three questions as being no longer applicable to the proposed development program. The Oklahoma State Health Department collaborated in the revision. The questions eliminated had to do with storage requirements for Oklahoma City, economic benefits accruing from such storage, and practical limitations as to the storage location.

The specific problems covered by the investigation, as propounded by the U. S. Engineer Department and endorsed by the Oklahoma State Health Department, were to determine:

A. Storage capacities that should be provided in reservoirs on the North Canadian River for correction of stream pollution conditions, and the desirable rate of release for that purpose.

B. Estimated monetary value, on an acre-foot basis, of water stored for stream pollution abatement.

C. The effect that the storage of waters in reservoirs on the North Canadian River may have on present methods of water softening and purification at Oklahoma City.

All available data relating to physiographic, hydrometric, climatic and economic conditions in the basin, together with general water supply and pollution problems, have been assembled and are presented, in summary discussions and tabulations, in Section One. Available supplemental data, where applicable, are inserted in the question discussions.

Requisite to proper analysis of the propounded questions are reliable analytical and factual data on pollution trends and chemical quality under various flow conditions. The extreme paucity of these basic data made it necessary to apply a mathematical approach in the analysis of questions "A" and "C". Methods used are based on the experience of the U. S. Public Health Service on similar investigations in other sections. Should the proposed development materialize, observations of pollution trends should be instigated, through the Oklahoma State Health Department, to make necessary adjustments in stream flows under actual operating conditions.

Problem analyses are segregated following the order outlined.

Question A. Storage capacities that should be provided in reservoirs on the North Canadian River for correction of stream pollution conditions, and the desirable rate of release for that purpose.

Analysis of this problem results in the following conclusions:

(1) Organic pollution abatement by stream regulation from conservation storage should be combined with reasonable treatment of organic waste prior to discharge.

(2) It is infeasible to provide minimum stream flows sufficient properly to dilute brine waste in the quantities produced from oil fields at and below Oklahoma City.

(3) Stream flow regulation from 40,000 acre-foot storage capacity at Canton would provide necessary minimum dilutions for downstream organic waste, provided the daily B.O.D. load from Metropolitan Oklahoma City does not exceed 12,000 pounds as measured at 20-day, 20°C. (Equivalent 90% reduction in B.O.D. of present waste.) Minimum treatment of waste from other riparian communities should be equivalent to 85% reduction of first stage B.O.D.

(4) Disregarding downstream inflow, the desirable rate of release from the Canton Reservoir is as follows:

June - September	160 c.f.s.
October - November	50 c.f.s.
December - February	25 c.f.s.
March - May	50 c.f.s.

A discussion of the computations made to arrive at these conclusions is presented in the following paragraphs.

General: Under the present development plan for the North Canadian Basin, such conservation storage as may be provided for pollution abatement would be included in the Canton Reservoir (mile 394). Within time limitations, factual and analytical investigations of pollution below Canton were pursued. Exclusive of Woodward (mile 468) sources of pollution above Canton are limited to problems of local significance.

Organic Pollution

Above Oklahoma City to Woodward, the North Canadian River receives waste directly from six municipalities, representing 25,000 equivalent sewered population, while in the lower 270 miles, five cities contribute waste from a sewered population equivalent to about 520,000. The practice of discharging raw industrial waste to the stream should be discontinued. Such waste should receive proper treatment prior to discharge, either in the municipal systems or by individual plants.

Metropolitan Oklahoma City: Oklahoma City maintains a dual sewerage system. The northern system, serving a residential area, receives 25% of the total sewage flow from 40% of the actual sewered population. This system discharges to the Deep Fork River. The southern system, with effluent to the North Canadian River, serves the business and industrial districts of the metropolitan area, and handles 75% of the total sewage flow from 60% of the actual sewered population. On a basis of loadings, as measured by the 5-day biochemical oxygen demand (B.O.D.) test at 20°C, the north side plant handles about 7,000 pounds of B.O.D. per day, while the load to the south side plant averages 85,400 pounds. Present treatment at both plants consists of chemical precipitation.

At Oklahoma City the industrial waste load on the south side plant includes 3 packing plants, 2 slaughter houses, 2 breweries, 5 milk plants, 4 creameries, and numerous miscellaneous service industries. Data as to animals slaughtered in Metropolitan Oklahoma City for an average and maximum week are as follows:

Animals Slaughtered Metropolitan Oklahoma City:

	Beef	Calves	Lambs	Hogs	Totals
Average Week	3300	2900	2400	5100	13,700
Maximum Week	6300	5800	5500	8600	26,200

Brewery production averages 20,000 barrels per month during the warmer season and 7,000 barrels per month in winter. (Beer barrel equals 32 U. S. gallons.)

At the south side plant, weighted 24-hour composite samples of influent waste for B.O.D. determinations were collected at hourly intervals for 18 days from October 14, 1939, to November 5, 1939. Data on these determinations are shown in Table 6.

Table 6 - Results of Biochemical Oxygen Demand Determinations of Weighted 24-hour Composite Influent Samples, Collected Hourly, at South Side Plant, Oklahoma City.

Date 1939	Sewage Flow M.G.D.	B.O.D. 5-day 20°C	Date 1939	Sewage Flow M.G.D.	B.O.D. 5-day 20°C
Oct. 14	13.9	520	Oct. 23	13.1	440
Oct. 15	10.9	470	Oct. 24	11.8	670
Oct. 16	13.1	1610	Oct. 25	15.0	595
Oct. 17	13.5	1540	Oct. 30	12.5	630
Oct. 18	14.9	2060	Oct. 31	13.7	505
Oct. 19	15.2	650	Nov. 1	13.7	660
Oct. 20	14.5	690	Nov. 2	13.7	535
Oct. 21	14.2	475	Nov. 3	13.7	645
Oct. 22	10.5	390	Nov. 5	10.0	340
	Weighted Averages			13.4	765

From parallel factual investigations, the high B.O.D. values of October 16, 17 and 18 are explained as heavy tankage waste from the packing industry. Where such material must be handled by municipal plants, it should be under regulated discharge.

Weighted 8-hour composite samples of raw waste were collected hourly for B.O.D. determinations on 4 days, between October 19 to 26, 1939. These data are shown in Table 7.

Organic Pollution Abatement: Satisfactory disposal of municipal waste is normally accomplished by proper treatment plus dilution in surface streams. Control of organic pollution in the North Canadian River, with present erratic flows, would require treatment of municipal waste sufficient to produce stable effluents. Generally speaking, such refined treatment is not only expensive but difficult of consistent accomplishment. Effective primary and secondary treatment, equivalent to an 85% reduction in first stage B.O.D. is practicable and should be provided by all sewered communities in the basin.

The pollution load entering the North Canadian River from Metropolitan Oklahoma City controls the quantity of diluting water needed for abatement measures. In establishing minimum flows it seems equitable to reduce the daily loading at Oklahoma City to 12,000 lbs. of first stage B.O.D. (20°C). Such limitation would require a 90% B.O.D. reduction in strength of present waste and, as estimated, slightly less than 95% reduction in 1955. Conservation storage for pollution abatement has been computed on this supposition. However, flows needed with 85% and 95% reduction in first stage B.O.D. at Oklahoma City are shown.

Table 8 shows, by cities, pertinent factual data as to water supply and sewerage for the area from Woodward to Wolcetka. Discrepancies between sewered populations and those served by water supply result from the laxity of sewer connections following recent service extensions. Table 9 tabulates analytical data for these cities, together with measured sewage flows and computed first stage B.O.D. loadings (La), for seasonal water temperatures.

Required Dilutions: For normal riparian uses of the North Canadian River, the minimum dissolved oxygen (D.O.) residual should be 3 p.p.m. Excluding reoxygenation, minimum dilutions needed at Oklahoma City for various water temperatures are shown below, with corresponding flows at Canton.

Treatment	Dilution (cfs) Okla. City			Flow (cfs) at Canton		
Reduc. BOD*	27°C	14°C	8°C	27°C	14°C	8°C
85%	933	483	348	1355	804	580
90%	622	322	232	1036	537	387
95%	311	161	116	518	268	193

*B.O.D. measured as 20-day, 20°C.
Channel Losses for Low Flows (Canton to Oklahoma City) = 40%
(U. S. Engineer Office, Tulsa, Okla.)

In free-flowing streams, the effect of reoxygenation from atmospheric reaeration and biological activity, tends to restore the dissolved oxygen deficit through the critical zone of depression. The combined influence of deoxygenation and reoxygenation on progressive changes in dissolved oxygen values for the North Canadian River could be readily determined by laboratory observations under various flow conditions. From these data reliable constants could have been established. Zero flows during the investigation precluded this possibility. No results of previous stream studies are available. Constants of deoxygenation (K_1) and atmospheric reaeration (K_2) used in the computations are based on previous studies of the U. S. Public Health Service on other streams, with adjustments for North Canadian River conditions.

Streeter and Phelps*, in a study of oxidation and reaeration in the Ohio River, developed mathematical equations expressing the relations of these phenomena. In practical application in large streams the equations have checked very closely with laboratory observations. In shallow streams, such as the North Canadian River, stream bed conditions, coupled with biological activity, exert a pronounced influence on the rate of oxidation and reaeration. Data on channel conditions below Canton were carefully analyzed as a guide in establishing constants used in the computations.

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*H. W. Streeter and E. B. Phelps. "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Bull. 146, U. S. Public Health Service (1925)

Table 7 - Laboratory Results of B.O.D. Determinations on 8-hour Weighted Composite Samples of Raw Waste, Collected Hourly at South Side Plant, Oklahoma City, Oklahoma.

Date 1939	Shift (Time)	B.O.D.	Flow (M.G.)	Total Pounds B.O.D. per Shift	Per Cent of Daily Total B.O.D.
Oct. 19	7 AM - 3PM	655	5.25	28,600	34.5
	3 PM -11PM	685	6.55	37,400	45.0
	11 PM -7 AM	590	3.43	16,900	20.5
Day Total				82,900	100.0
Oct.23	7 AM -3 PM	415	4.7	16,300	33.7
	3 PM -11PM	525	5.55	24,200	50.0
	11 PM -7 AM	330	2.87	7,900	16.3
Day Total				48,400	100.0
Oct. 24	7 AM -3 PM	685	5.29	30,300	36.8
	3 PM -11PM	735	6.25	38,300	46.7
	11 PM -7 AM	505	3.24	13,600	16.5
Day Total				82,100	100.0
Oct. 25	7 AM -3 PM	590	5.45	26,800	36.4
	3 PM -11PM	675	6.3	35,400	48.0
	11 PM -7 AM	425	3.25	11,500	15.6
Day Total				73,700	100.0

All B.O.D. expressed as 5-day 20°C.

Table 8 - Factual Data on Sources of Municipal and Industrial Water Supply and Sewerage for Cities Tributary to the North Canadian River from Woodward to Weleetka, Oklahoma.

Source Pollution	River Miles	Source Water Supply	Population Served	Treatment Water Supply	Average Consump. M.G.D.	Sewerage System	
						Type	Treatment
Woodward	468	Wells	7,500	None	0.500	Separate	None
Mooreland	445	Wells	750	None	0.030	Separate	Primary
Seiling	421	Wells	650	None	0.010	Separate	Secondary
Canton	393	Wells	850	None	0.050	Separate	Secondary
Watonga	368	Wells	2,400	None	0.120	Separate	Septic Tank
Geary	349	Wells	2,000	None	0.115	Separate	Secondary
El Reno	317	Wells	11,000	Chl.	1.600*	Separate	Primary
Yukon	288	Wells	1,600	None	0.225	Separate	Secondary
Okla.City	265	N.Canadian R.	225,000	Chl. Filt.	14.410	Combined	Chem. Precip.
McCloud	208	Wells	600	None	0.030	Separate	Primary
Tecumseh	186	Impounded	2,000	Filtration	0.060	Separate	Secondary
Shawnee	185	Deer Creek	25,000	Chl. Filt.	1.500	Separate	None
Prague	150	Wells	1,000	None	0.030	Separate	Secondary
Earlsboro	148	Wells	1,200	None	0.050	Separate	Secondary
Wetumka	83	Impounded	2,200	Filtration	0.200	Separate	Secondary
Weleetka	70	Impounded	1,500	Filtration	0.083	Separate	None

* *Serves Federal Reformatory.*

Table 9 - Analytical data for cities discharging waste to the North Canadian River from Canton, Oklahoma, downstream, together with measured sewage flows and calculated B.O.D. loadings.

Municipality	Sewered Pop.	Flow M.G.D.	Raw Sewage B.O.D. p.p.m.					Raw Waste La 20°C	Treated Waste	
			5-day 20°C	La 20°C	La 27°C	La 14°C	La 8°C		% Red.	La 20°C
Canton	500	.022	312	456	520	401	346	84	85	13
Watonga	2,400	.130	145	212	242	187	162	230	85	35
Geary	1,500	.091	185	271	309	238	206	206	85	31
El Reno	9,000	.345	334	189	558	430	371	1407	85	211
Yukon	1,300	.056	240	351	401	309	266	164	85	25
Oklahoma City	143,000	13.4	765	1117	1275	984	850	124831	85	18725
Oklahoma City									90	12483
Oklahoma City									95	6241
McCloud	600	.024	374*	547	624	481	415	109	85	16
Tecumseh	2,400	.061	589	861	982	758	654	438	85	66
Shawnee	23,000	1.275	328	480	548	423	365	5100	85	765
Prague	1,000	.040	374*	547	624	481	415	192	85	27
Earlsboro	800	.032	374*	547	624	481	415	146	85	22
Wetumka	1,800	.072	374*	547	624	481	415	328	85	49
Weleetka	1,400	.056	374*	547	624	491	415	255	85	38
Eufaula	1,600	.064	374*	547	624	491	415	292	85	44

* *Computed from basic factual data.*

La = First stage B.O.D.

Using the Streeter-Phelps derivations in Appendix "B", minimum flows for seasonal temperatures were computed to meet treatment conditions stipulated under "Organic Pollution Abatement". These flows, above Oklahoma City and Canton, by seasons, are shown in Table 10.

Tables 11 - 11(b) indicate the dissolved oxygen and biochemical oxygen demand traverse from the Canton Reservoir to Wetumka as computed for temperatures of 27°C, 14°C, and 8°C, with treatment at Oklahoma City equivalent to 90% reduction in B.O.D.

Fig. 2 shows graphically, points of pollution on the North Canadian River below Canton, together with computed curves of seasonal flows, dissolved oxygen and biochemical oxygen demand trends.

Discussion: The following explanatory remarks refer to computed B.O.D. and D.O. trends shown in Tables 11 - 11(b).

(1) No consideration was given to inflows below the Canton Reservoir. Such flows as occur would be beneficial to pollution abatement.

(2) Channel losses were assumed to be uniform per mile below Canton. Below Oklahoma City, such losses were taken as 75% of those below Canton.

(3) Composite La and D.O. for small cities were computed on the average stream flow between respective points of pollution. In determining critical conditions below Oklahoma City, composite La and D.O. were based on combined stream flow and plant effluent, with adjustments for channel losses.

(4) All computations were based on first stage B.O.D. (La). Should the treatment plants produce effluents beyond the carbonaceous stage, the second stage oxygen demand on the critical section of the stream may appear higher than that indicated as La, but the computed rate of deoxygenation (K_1 for La) would decrease, with the net result of a less pronounced but prolonged oxygen sag.

Times of flow between points of pollution were computed from discharge-velocity curves furnished by the U. S. Engineer Office, Tulsa, Oklahoma, and reproduced in Fig. 3.

Fig. 4 shows, by curves, the relation between water temperatures and dilution requirements at Oklahoma City for various stages of B.O.D. reduction by treatment.

Conservation Storage for Pollution Abatement

From daily flow data at Canton for the years 1914 - 1938, (estimated by the U. S. Engineer Office at Tulsa, Oklahoma) the critical periods of low flow from the standpoint of reservoir operation for pollution abatement were:

Period	Storage Requirement*
Aug. 11, 1916 - Aug. 15, 1917	55,000
July 23, 1919 - July 10, 1920	36,000
June 1, 1922 - April 29, 1923	35,000
June 24, 1931 - Nov. 15, 1931	40,000
July 22, 1932 - April 24, 1933	37,000
April 12, 1934 - Oct. 18, 1934	34,000
July 10, 1935 - May 5, 1936	36,000
June 20, 1936 - Sept. 6, 1936	29,000

* Based on required flow with 90% reduction in first stage B.O.D. by treatment, Oklahoma City (Table 10)

From these data, 40,000 acre-feet of storage would have yielded sufficient water to augment low stream flows except for the period July 20 - August 15, 1917. Storage capacity of about 55,000 acre-feet would be required to cover this abnormal drouth. Considering available supply, together with normal water uses, it appears more equitable to allocate 40,000 acre-feet storage for pollution abatement, at the risk of a recurrence of the 1916 - 1917 conditions, than to reserve 15,000 additional acre-feet for use about once in 20 years. Should conditions approaching 1916 - 1917 recur, the computed dissolved oxygen residual of 3 p.p.m. would be a factor of safety against occurrence of miasmatic nuisance conditions below Oklahoma City.

Reservoir behavior for the critical flow periods, with 40,000 acre-foot storage (plus 10,000 acre-feet permanent pool) using evaporation rates established in Table 4, Section One, are computed in Table 15, Question "C".

Table 10 - Minimum Seasonal Flows, in C.F.S., above Oklahoma City and Canton, for Organic Pollution Abatement, with Indicated Reductions, by Treatment, in B.O.D. at Oklahoma City.

Season	*Reduction B.O.D., Oklahoma City by Treatment					
	85%		90%		95%	
	CFS	Acre-Ft.	CFS	Acre-Ft.	CFS	Acre-Ft.
Oklahoma City						
June - Sept.	160	39,040	95	23,180	45	10,980
Oct. - Nov.	55	6,710	30	3,660	10	1,220
Dec. - Feb.	25	4,500	15	2,700	10	1,800
March - May	55	10,120	30	5,520	10	1,840
Weighted Ave.	82		49		22	
Total		60,370		35,060		15,840
Canton						
June - Sept.	275	67,100	160	39,040	72	17,568
Oct. - Nov.	90	10,980	50	6,100	20	2,440
Dec. - Feb.	45	8,100	25	4,500	20	3,600
March - May	90	16,560	50	9,200	20	3,680
Weighted Ave.	140		81		38	
Total		102,740		58,840		27,288

* *B.O.D. as total first stage.*

Table 11 - Dissolved Oxygen and Biochemical Oxygen Demand Traverse, Canton Reservoir to Wetumka, Water Temperature at 27°C and Treatment at Oklahoma City Equivalent to 90% Reduction in B.O.D.

Point	Mileage (above Mouth)	Between Points		At Point		
		Ave. Disch. c.f.s.	Time of Flow Days	Dissolved Oxygen p.p.m.	% Sat.	B.O.D. Remaining 1st Stage 27°C.
Reservoir	394					
Canton	382	159.5	0.1	7.3	90	1.7
				7.3	90	1.7
Watonga	368	152.9	1.1	7.5	93	1.2
				7.4	91	1.2
Geary	349	149.0	0.9	7.6	94	0.9
				7.6	94	1.0
El Reno	317	129.5	1.5	7.8	96	0.6
				7.7	95	1.0
Yukon	288	114.5	1.4	7.8	96	0.7
				7.8	96	0.7
Oklahoma City	265	101.7	1.1	7.8	96	0.5
				6.7	83	24.1
Critical Pt.	229	111.9	1.6	3.0	37	14.5
McCloud	208	104.2	0.9	3.4	42	11.0
				3.4	42	11.0
Tecumseh	186	98.4	1.0	4.2	52	8.1
				4.2	52	8.2
Shawnee	165	95.3	0.05	4.3	53	9.1
				4.2	52	9.6
Prague	150	90.4	1.6	5.3	65	5.8
				5.3	65	5.8
Earlsboro	148	85.5	0.1	5.3	65	5.7
				5.3	65	5.7
Wetumka	83	76.5	3.1	6.9	85	2.1

Dilution: Oklahoma City 96 c.f.s.; Canton 160 c.f.s.
K_1 = 0.1; K_2 = 0.35 (20°C)
Revised mileage data, received from U. S. Engineer Dept., on December 22, 1939, indicate slight variations from the figures used. The deviations would not appreciably change the indicated trends.

Table 11(a) - Dissolved Oxygen and Biochemical Oxygen Demand Traverse, Canton Reservoir to Wetumka, Water Temperature at 14°C and Treatment at Oklahoma City Equivalent to 90% Reduction in B.O.D.

Point Under Consideration	Mileage (above Mouth)	Between Points		At Point		
		Ave. Disch. c.f.s.	Time of Flow Days	D. O. p.p.m.	D. O. %	1st Stage B.O.D. p.p.m.
Reservoir	394					
Canton	392	50	0.1	9.3	90	1.3
				9.3	90	1.3
Watonga	368	48	1.4	9.8	94	1.0
				9.8	94	1.2
Geary	349	44.5	1.1	10.0	96	1.0
				9.9	95	1.1
El Reno	317	40.5	1.9	10.1	97	0.8
				10.0	96	1.7
Yukon	288	36	1.8	10.0	96	1.3
				10.0	96	1.4
Oklahoma City	265	32	1.5	10.0	96	1.1
				6.2	65	42.6
Critical Pt.	230	48.7	1.9	3.0	30	30.7
McCloud	208	45.4	1.3	3.5	34	25.3
				3.5	34	25.4
Tecumseh	186	42.8	1.3	4.4	42	20.2
				4.4	42	20.4
Shawnee	185	41.5	0.1	4.5	43	20.2
				4.2	43	22.3
Intermed. Pt.			(1.0)	5.1	49	
Intermed. Pt.			(1.5)	5.4	52	
Prague	150	39.8	2.1	5.7	55	15.6
				5.7	55	15.7
Earlsboro	148	37.1	0.1	5.8	56	15.4
				5.8	56	15.5
Wetumka	83	33.2	4.0	8.0	77	7.7

Dilution: Oklahoma City 30 c.f.s.; Canton 50 c.f.s.
K_1 = 0.1; K_2 = 0.35 (20°C)

Table 11(b) - Dissolved Oxygen and Biochemical Oxygen Demand Traverse, Canton Reservoir to Wetumka, Water Temperature at 8°C and Treatment at Oklahoma City Equivalent to 90% Reduction in B.O.D.

Point Under Consideration	Mileage (above Mouth)	Between Points Ave Disch. c.f.s.	Between Points Time of Flow Days	At Point D. O. p.p.m.	At Point D. O. %	At Point 1st Stage B.O.D. p.p.m.
Reservoir	394					
Canton	392	21.7	0.2	10.7	90	1.1
				10.7	89	1.2
Watonga	368	20.8	2.0	11.4	96	0.9
				11.3	05	1.2
Geary	349	19.3	1.6	11.5	97	1.0
				11.4	97	1.2
El Reno	317	17.6	2.8	11.6	97	0.8
				11.3	95	2.6
Yukon	288	15.6	2.6	11.4	96	1.9
				11.4	96	2.1
Oklahoma City	265	13.8	2.3	11.5	97	1.6
				4.5	38	54.2
Critical Pt.	240	32.8	1.6	3.0	25	43.8
McCloud	208	30.6	2.1	3.9	33	34.6
				3.9	33	34.6
Tecumseh	188	28.4	1.5	5.0	42	28.4
				5.0	42	28.6
Shawnee	185	27.5	0.1	5.0	42	28.3
				4.7	40	30.2
Intermed.Pt.			(1)	5.4	45	
Intermed.Pt.			(2)	6.1	51	
Prague	150	26.0	2.5	6.5	55	21.8
				6.5	55	21.9
Earlsboro	148	24.5	0.1	6.6	55	21.5
				6.6	55	21.6
Wetumka	83	21.9	5.0	9.1	76	11.2

Dilution: Oklahoma City 13 c.f.s.; Canton 2 c.f.s.
K_1 = 0.1; K_e = 0.35 (20°C)

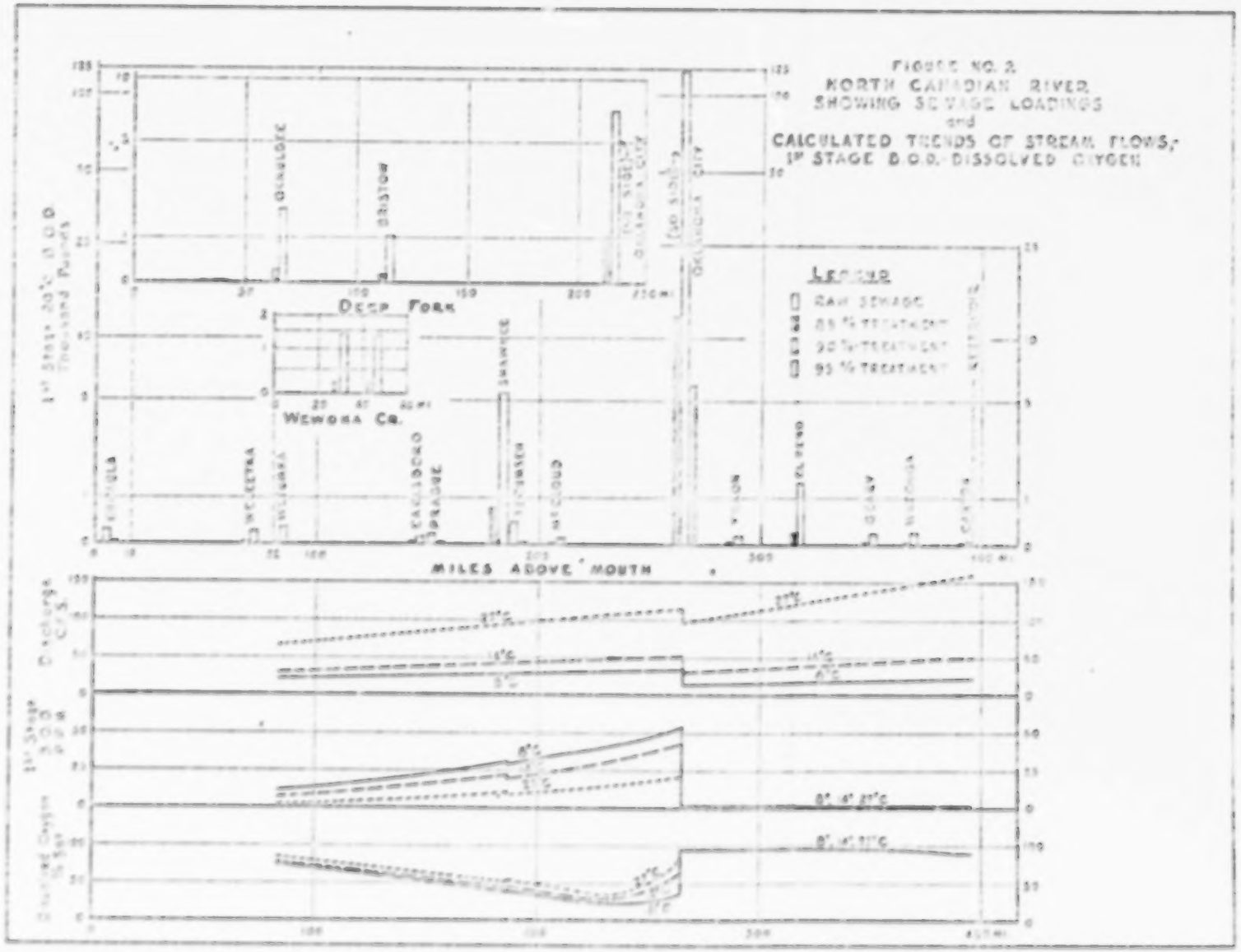


FIGURE NO. 2
NORTH CANADIAN RIVER
SHOWING SEWAGE LOADINGS
and
CALCULATED TRENDS OF STREAM FLOWS,
1st STAGE B.O.D.- DISSOLVED OXYGEN
LEGEND
RAW SEWAGE
85 % TREATMENT
90 % TREATMENT
95 % TREATMENT
DEEP FORK
WEWOKA CR.
MILES ABOVE MOUTH

16-8

FIGURE NO. 3

NORTH CANADIAN RIVER, OKLA.

AVERAGE VELOCITY - DISCHARGE CURVE

PRODUCED FROM DATA BY

U.S. ENGINEER OFFICE TULSA, OKLAHOMA

Note: Based on discharge observations from February 2, 1938 to September 8, 1939

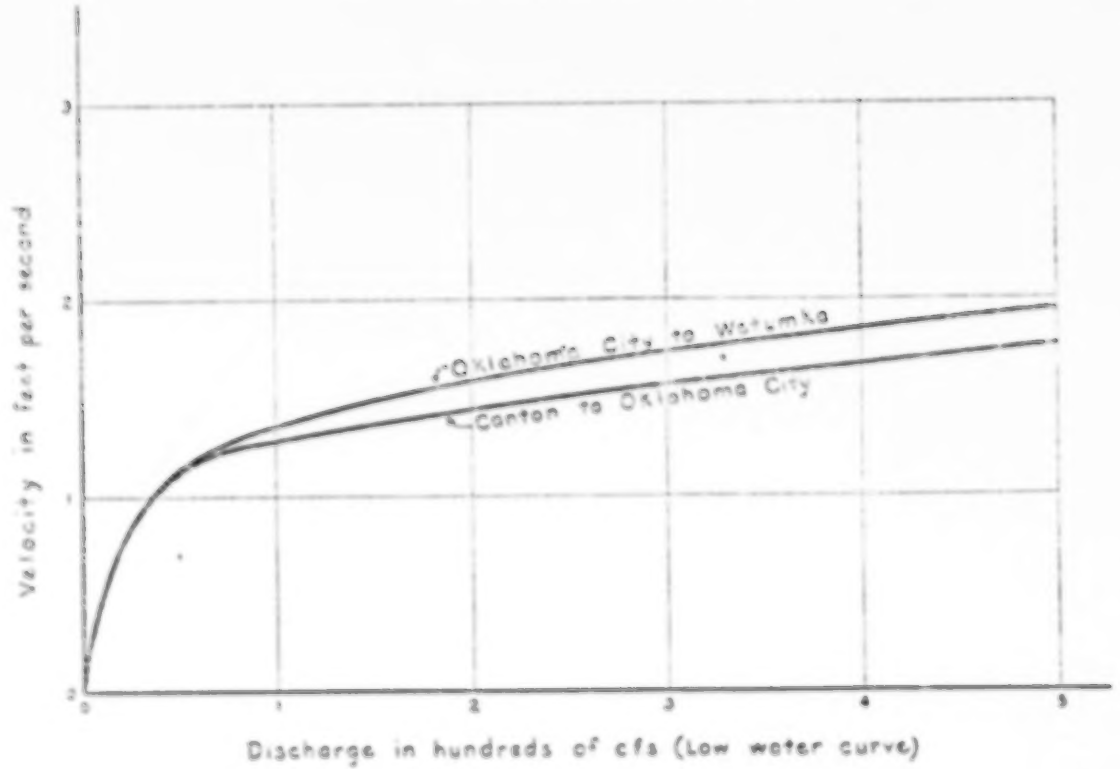
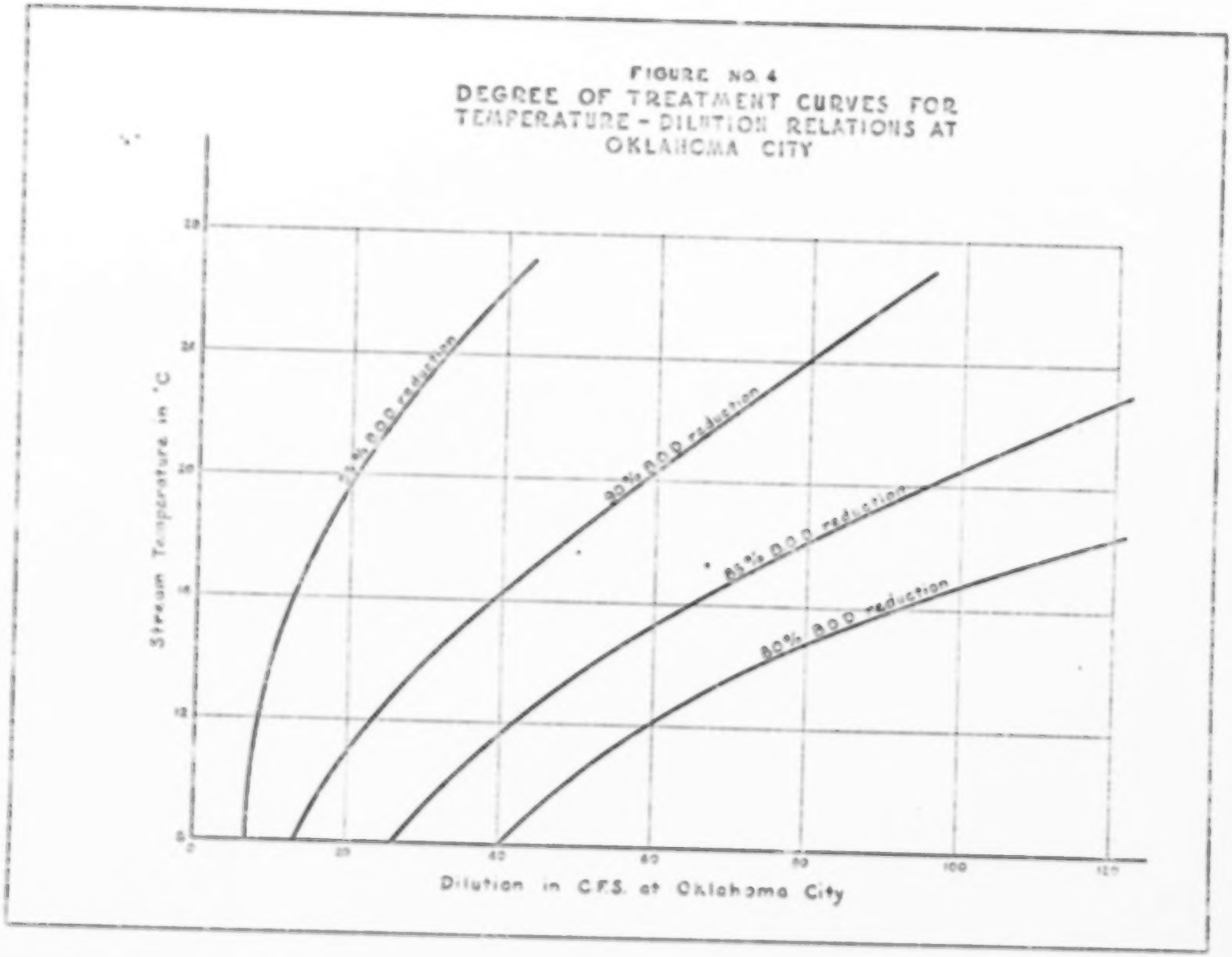


FIGURE NO. 4

DEGREE OF TREATMENT CURVES FOR TEMPERATURE - DILUTION RELATIONS AT OKLAHOMA CITY



Chemical Pollution

Excessive mineralized pollution of the North Canadian River results from oil field brine waste reaching the stream at points from Oklahoma City to the mouth. Available figures indicate an average daily production of 87,500 barrels of oil from about 2000 producing wells located in the area tributary to the main stem.

The ratio of brine waste to oil produced varies for different wells, being influenced by locality, formation, pumpage rates, and age of well. However, the average for the basin is approximately 3 barrels of brine per barrel of oil. Table 12, compiled from estimates of the Oklahoma Planning & Resources Board, shows oil production, by counties, together with resulting waste, and the equivalent brine, in barrels, reaching the watershed of the North Canadian River.

These data indicate that of 208,000 barrels of brine produced daily, only 73,000 barrels, or 35%, is controlled by reinjection in subsurface formations or diverted to evaporation ponds. No data are available as to quantities of remaining brine actually reaching the river channel.

From the local Petroleum Experiment Station* the following data were secured as to the chloride content of brine waste, by formation, from the Oklahoma City Fields:

Formation	Chlorides in p.p.m.
Wilcox	31,900 to 163,000
Simpson	94,000 to 184,400
Johnson Sand	138,300 to 237,600
Arbuckle	136,200 (Single Sample)

The wide variations in chloride content of brines produced in the same formation in a given field is probably influenced by inflow of upper sand waters. From these data, the best available at present, the average chloride content of brine

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* *Bartlesville, Okla. Bureau of Mines, U. S. Department of Interior. Data secured through the Oklahoma State Health Dept. and the Oklahoma Planning and Resources Board.*

waste from the field would exceed 100,000 p.p.m. Allowing only 100 p.p.m. chlorides in the stream, a dilution ratio of about 250 to 1 would be required to check chloride concentration in the channel at approximately 500 p.p.m. (High for public water supplies, questionable for irrigation, probably satisfactory aquatic life and stock watering.)* Of the brine deposited on the watershed, if 50% actually reached the channel, at a uniform rate, dilution flows above 1000 c.f.s. would be required. Obviously, maintenance of such minimum flow is infeasible.

Practical control of oil field waste appears to be reinjection in subsurface formations, other than fresh water strata, with evaporation ponds possibly used where quantities are small. If ponding with diversion to the main channel is practiced, quantities should be controlled within limits of dilutions as finally established. During peak flows, rates of diversion may be proportionally increased, provided the stream does not reach flood stages. Accurate data as to sources, quantities and qualities of brine produced are prerequisite to effective control measures.

Fig. 5 illustrates, by dilution capacity curves, permissible organic and chemical loadings. Chloride content in the concentrations provided would not appreciably affect oxidation phenomena of organic pollution.

Question B. Estimated monetary value, on an acre-foot basis, of water stored for stream pollution abatement.

The estimated monetary value of stored water, as related to organic pollution abatement, is computed to be $38. per acre-foot. (Using 59,000 acre-feet - Table 10.)

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* *Public Health Reports, Drinking Water Standards, Reprint 1029 - p.24.*

"*Contamination of Domestic Water Supplies by Inadequate Plugging Methods or Faulty Casing*" - *Collaborated Report U. S. Bureau of Mines and Kansas State Board of Health pp. 3, 4, and 5.*

"*Critical concentrations toxic salts irrigation waters ..... sodium chloride 350 p.p.m..... ordinarily total sodium salts not exceed 700 p.p.m.*" - *1 - 1 - 400, U. S. Dept. of Health from Bureau Chemistry & Soils, Washington, D. C.*

Table 12 - Estimated Producing Oil Wells with Oil and Brine Production Figures, expressed by Counties, for the area draining direct to the main stem of the North Canadian River. (From basic data, Oklahoma Planning & Resources Board, secured through the Oklahoma State Board of Health).

County	River Mileage	Est. Producing Wells	Daily oil Production Bbls.	Daily Bbls. Brine Waste			Volume of Brine on Watershed	
				Total	Controlled	Discharged on Watershed	Mean c.f.s.	Acre-feet per day
Oklahoma	215-280	880	77,500	115,000	40,000	75,000	4.90	9.80
Pottawatomie	158-215	200	3,000	30,000	15,000	15,000	0.97	1.93
Seminole	125-158	300	3,000	30,000	10,000	20,000	1.30	2.60
Okfuskee	59-148	400	2,000	20,000	5,000	15,000	0.97	1.93
Hughes	59-90	200	2,000	13,000	3,000	10,000	0.65	1.30
Totals	280-59	1980	87,500	208,000	73,000	135,000	8.79	17.56

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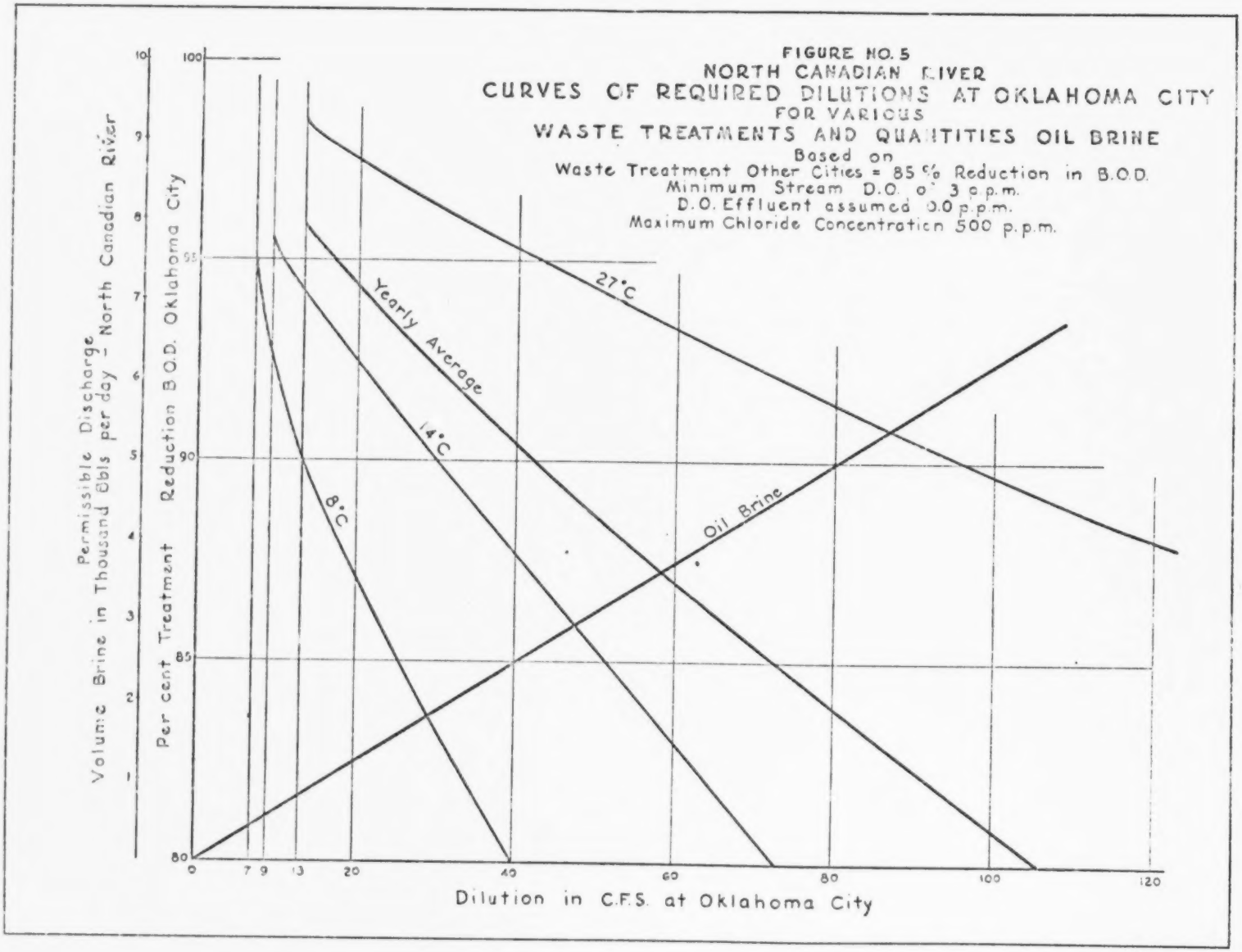
FIGURE NO. 5
NORTH CANADIAN RIVER
CURVES OF REQUIRED DILUTIONS AT OKLAHOMA CITY
FOR VARIOUS
WASTE TREATMENTS AND QUANTITIES OIL BRINE
Based on
Waste Treatment Other Cities = 85 % Reduction in B.O.D.
Minimum Stream D.O. of 3 p.p.m.
D.O. Effluent assumed 0.0 p.p.m.
Maximum Chloride Concentration 500 p.p.m.
Permissible Discharge
Volume Brine in Thousand Bbls per day - North Canadian River
Per cent Treatment Reduction B.O.D. Oklahoma City
27°C
Yearly Average
14°C
8°C
Oil Brine
Dilution in C.F.S. at Oklahoma City

Analysis of the problem is described in the following paragraphs.

General: Under question "A" of this report, sources of organic pollution reaching the North Canadian River below the proposed Canton Dam were discussed in detail, together with necessary minimum seasonal dilutions that would, when combined with stipulated treatment, obviate odoriferous nuisances and maintain a dissolved oxygen residual of 3 p.p.m. through the critical zone of oxygen depression.

Consistent with available data, the most equitable engineering method of computing the tangible monetary value of the conservation storage necessitated determining costs of supplemental treatment that would produce stable effluents. The supposition of this approach is that organic pollution in the channel of the North Canadian River below Canton will be controlled either with waste treatment plus regulated minimum flows, or by extended waste treatment alone. As related to sewage disposal the cost of completing the oxidation process, by substituting extended waste treatment for diluting water, would represent the tangible monetary value of adjudicated conservation storage.

Analysis: Organic pollution abatement with recommended minimum flows, set up in Question "A", is contingent upon the 12 sewered communities below Canton providing treatment equivalent to the first stage B.O.D. reduction of 85%, excepting that the reduction at Oklahoma City would be 90%. These indicated flows would be sufficient for future growth expectancy at all sewered communities except Oklahoma City. Computations for additional treatment that would complete the oxidation process were based on these conditions.

Supplemental treatment was designed as intermittent sand filters and controlled chlorination with 15 minutes contact, excepting that for Oklahoma City, extended biological treatment by activated aeration was figured in lieu of sand filter units.

Design figures used in the computations were based on detailed analysis of influent wastes to be treated, local conditions affecting cost, and actual experience on similar problems in other sections of the United States. Land cost and engineering were not included. Sand filter units were

designed with 3 feet depth and maximum loadings of 500,000 gallons per acre per day. Supplemental activated aeration at Oklahoma City was on a basis of 2.5 hour retention. Chlorine dosages were computed on an average of 30 pounds per million gallons of treated sewage.

Summary of computed installation cost of providing supplemental treatment at the 12 sewered communities below the Canton Reservoir, is as follows:

Sand Filter-Chlorination Units (11)	-	$212,000
Activated Aeration at Oklahoma City	-	600,000
Total		$812,000

The life value of the conservation storage would continue subsequent to the 15-year obsolescence period for the designed treatment units. Annual charges computed for complete stabilization following stipulated treatment, with no growth allowance for the 11 communities beyond the 15-year expectancy, are as follows:

(Complete stabilization following 90% Removal first stage B.O.D. at Oklahoma City)

Interest (5% of $812,000)	-	$40,600.00
Amortization of obsolescence (.0463 x 812,000)	-	37,595.60
Operation and maintenance	-	35,000.00
Total Annual Charge	-	113,195.60
Capitalized at 5%	-	2,263,912.00
Value stored water per acre-ft. (Using 59000 A.F. - Table 10)	-	37.73
Say	-	38.00

Discussion: Analysis indicates the computed costs to be comparable to averages for actual installation of similar units through the United States. As computed, installation cost of sand filter units averages $14,000 per acre, with operation and maintenance below 28 cents per capita capacity.

As measured at 5-day 20°C, the effluent at Oklahoma City, with 90% treatment would have 76.5 p.p.m. B.O.D. This effluent is comparable to a normal municipal sewage subsequent to primary treatment. The computed installation cost of activated sludge treatment to stabilize this effluent is below $45,000 per million gallon capacity. Annual operation cost figured about $1100 per million gallon capacity.

Decrease in treatment at Oklahoma City to 85% B.O.D. reduction, or an increase above 95%, so affects the mathematical relation between required dilutions and cost of supplemental treatment, as to appreciably reduce the acre-foot value of conservation storage.

These computations represent the best approach that can be made consistent with data available for analysis. Unless more reliable data can be secured, other benefits accruing from adjudication of the conservation storage for stream regulation are considered intangible. Monetary benefits from oil field pollution abatement are not included. However, minimum flow regulation would permit more intelligent design of impoundments for regulated discharge. Benefits to stock watering, wild life, and recreation would also result from stream regulation. These benefits, especially stock watering, are definitely of economic value, but are extremely difficult to invoice in dollars.

Question C. The effect that the storage of waters in reservoirs on the North Canadian River may have on present methods of water softening and purification at Oklahoma City.

Summary of Conclusions reached:

(1) As related to present methods of water softening and purification at Oklahoma City, the principal effect of conservation storage in upstream channel reservoirs will be to increase alkalinity of waters reaching Oklahoma City.

(2) The alkalinity of waters in the North Canadian River varies, averaging from about 180 to 200 p.p.m. for flows below 100 c.f.s., and about 120 to 150 p.p.m. for flows exceeding 100 c.f.s.

(3) With no upstream reservoirs, Oklahoma City could select, for storage, sufficient waters in the average alkalinity range of 120 to 140 parts per million.

(4) Should the proposed Canton reservoir be operated with 40,000 acre-feet storage capacity for stream regulation, Oklahoma City could select, for storage, sufficient waters in the average alkalinity range of 130 to 150 parts per million.

(5) Insufficient data exist upon which to base conclusions as to the effect biological development in the Canton reservoir may have on water treatment problems at Oklahoma City. However, if conservation storage at Canton is limited to 40,000 acre-feet, it is doubtful if the diluted water from the Canton storage would exert much influence on the biological development in the Oklahoma City reservoir.

(6) Conservation storage at Canton would have no detrimental effect on the bacterial quality of waters reaching Oklahoma City.

Analysis of the problem is in the following paragraphs.

The source of water supply for Oklahoma City is the North Canadian River. Because of variations in the chemical quality of river flows, selective impounding is practiced in the interest of water treatment economy.

Analysis of the probable effect upstream storage may have on selectivity at Oklahoma City is based on 50,000 acre-feet storage at Canton, of which 40,000 acre-feet is for pollution abatement. Regulated seasonal discharges were taken as established in Table 10, Question "A", assuming 90% first stage B.O.D. reduction, by treatment, at Oklahoma City.

Water Supply - Oklahoma City

Present storage of water for Oklahoma City is in an artificial off-channel reservoir, Lake Overholser, located 10 miles west of the city. The east bank of the lake is the west bank of the river channel, and a concrete dam extending westward from the river's east bank, dams that stream and forms the south end of the lake. Earthen dykes form the west and north banks of the lake, with a low concrete weir section at the northeast end forming a "roll-over" into the lake.

The level of the river channel is regulated by gate locks in the river dam. On filling the lake, water backs up a large slough or natural presediment basin before overflowing the weir section of the "roll-over". Lake Overholser covers 1,700 acres at capacity of 17,000 acre-feet.

Consumption: The present water consumption of Oklahoma City averages 13.5 M.G.D., or is equivalent to a daily per capita consumption of about 64 gallons. According to city officials, and substantiated by field investigations, the present low capita consumption is due to quantity limitations and distribution inadequacies. Expansions and corrections in the distribution system are proposed for early construction. Consumption in 1960 is estimated at 27 M.G.D., or about 30,000 acre-feet annually.

Treatment: Water treatment at Oklahoma City includes coagulation, lime softening, settling, carbonation, filtration and chlorination. The present water treatment plant, completed in 1923, is rated at 16 M.G.D. capacity. It operates well above design capacity during summer months. From records of the Oklahoma City Water Department, the quality of raw water entering the treatment plant for the years 1926-1938 averages 163 p.p.m. alkalinity; 76 p.p.m. non-carbonate hardness; and 239 p.p.m. total hardness.

Proposed Storage: The storage capacity provided by Lake Overholser is considered inadequate. A report[a] covering proposed water supply and water works improvement was released by Oklahoma City on November 8, 1939. This report recommends the continued use of the North Canadian River as a source of supply, with construction of an off-channel storage reservoir, of 75,000 acre-feet capacity, about 4.5 miles northwest of Oklahoma City. This project, known as the "Upper Bluff Creek Reservoir", is estimated to cost $4,345,000. The reservoir will be filled by gravity using a 4.5-mile canal of 1500 c.f.s. capacity.

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[a] *"A Proposed Water Supply and Water Works Improvement for the City." - Committee of the Oklahoma City Engineering Club. - November 6, 1939.*

Alkalinity North Canadian River: Subsequent to January 1934, the Oklahoma City Water Department has made, with few exceptions, daily alkalinity determinations of samples of river water, collected above Oklahoma City. These results, together with a few determinations by the Oklahoma State Health Department were available for analysis.

Table 13 summarizes the alkalinity data by years, showing weighted average alkalinity for indicated discharges at Canton. The computations indicate an average alkalinity range of about 180 to 200 p.p.m. for flows of 100 c.f.s. or less, while for flows exceeding 100 c.f.s., the average range is from about 120 to 150 p.p.m. An average alkalinity-flow curve, based on these data, is developed in Fig. 6, for flows up to 1000 c.f.s. Limited data on flows above 1000 c.f.s. indicate an average alkalinity of about 120 p.p.m.

By projecting these average alkalinity-flow relations to the daily discharge records at Canton for the years 1914 - 1938, the comparison between weighted alkalinity and quantities of run-off, by years, under various flow conditions, are shown in Table 14.

These data indicate that under present stream conditions, Oklahoma City could, by selectivity, impound sufficient water for its needs in the average alkalinity range of 120 to 140 p.p.m. It appears, also, that upstream flood control reservoirs would have little effect on the alkalinity of selected waters.

Effect of Channel Storage on Selectivity at Oklahoma City

To determine the probable trends in chemical quality of river water with Canton reservoir operated for pollution abatement, an effort has been made to duplicate, hypothetically, reservoir operations for selected known critical periods of flow. In establishing discharges at Canton for pollution abatement no consideration was given to inflow below the Canton Reservoir.

The computed fluctuations in reservoir capacity and alkalinity were based on the mathematical relations:

Table 13 - Summary of Alkalinity Data North Canadian River Showing Weighted Alkalinities for Indicated Flows at Canton, Oklahoma, for the Years 1934-1938. (Alkalinity data from daily records Oklahoma City Water Department.)

Year	Weighted Alkalinity, in p.p.m., for Flows of:									
	0-50 cfs	51-100 cfs	101-250 cfs	251-350 cfs	351-450 cfs	451-550 cfs	551-650 cfs	651-750 cfs	751-850 cfs	851-1000 cfs
1934	168	183	128	134	147	130	110	100	152	147
1935	209	163	156	159	130	145	160	130	130	136
1936	237	179	169	144	157	149	141	-	-	134
1937	203	200	138	137	144	134	142	134	139	131
1938	190	168	153	150	145	184	142	142	126	133
1939	204	189	145	146	177	150	168	-	146	174
Wtd* Ave.	202	179	150	149	144	140	146	134	135	128

* *Averages weighted by number of samples available for annual average.*

Table 14 - Relation Between Run-off, in acre-feet, and Weighted Average Alkalinity, in ppm, by years, for the North Canadian River at Canton, Oklahoma, for the Period 1914-1938.

Year	0-100 cfs		101-250 cfs		251-500 cfs		501-1000 cfs		Over 1000 cfs		Annual Discharge	Weighted Alkalinity
	Acre-ft.	Ave.* Wtd. Alk.	Acre-ft.	Ave. Wtd. Alk.	Acre-ft.	Ave. Wtd. Alk.	Acre-ft.	Ave. Wtd. Alk.	Acre-ft.	Ave. Wtd. Alk.	Acre-ft.	p.p.m.
1914	21576	196	19210	180	22790	144	--	-	86529	120	150306	140
1915	13852	186	--	-	15740	144	107140	134	368480	120	561162	127
1916	28094	191	9590	183	--	-	39780	146	200100	120	277564	129
1917	11886	179	15960	138	29290	140	49070	135	--	-	105806	142
1918	12900	200	32520	146	75080	142	22590	140	--	-	153090	138
1919	13905	193	30765	160	45440	142	57960	145	--	-	148070	151
1920	17110	190	18920	150	37570	149	--	-	175550	120	249150	132
1921	17000	182	14150	159	71960	144	--	-	69620	120	172730	140
1922	14065	186	28610	162	29268	140	77186	136	--	-	149129	147
1923	18601	198	--	-	24330	144	--	-	753980	120	796651	124
1924	11210	182	57730	163	39600	148	--	-	--	-	108540	155
1925	24320	186	29760	154	39850	146	--	-	--	-	93920	159
1926	16260	184	19800	150	28120	143	31170	140	--	-	165450	147
1927	12380	202	105154	155	26280	155	35280	140	--	-	182814	152
1928	20500	188	26340	148	25530	144	111440	128	--	-	192810	140
1929	16350	186	59650	180	17400	148	--	-	--	-	93400	157
1930	21960	194	8630	153	45790	146	45010	134	--	-	121390	151
1931	19458	186	22080	150	69010	148	--	-	--	-	110545	153
1932	4236	202	69810	154	--	-	--	-	64590	120	138636	140
1933	23290	192	--	-	24340	144	65810	140	--	-	112840	151
1934	23177	191	34080	149	--	-	--	-	--	-	93027	156
1935	11531	193	11190	148	44680	143	35760	146	--	-	244801	131
1936	18952	194	--	-	--	-	--	-	177100	120	254922	129
1937	18688	198	33760	152	--	-	33790	146	208180	120	307862	131
1938	19989	201	--	--	22360	144	55080	128	187410	120	310899	137
							87840	135	88660	120		

* Average Weighted Alkalinity.

Table 15 - Hypothetical Operation of the Proposed Canton Reservoir, Showing Fluctuations in Conservation Storage and Alkalinity for Critical Flow Periods. (Reservoir Capacity 50,000 acre-feet).

Total Storage 50,000 acre-feet						Dead Storage 10,000 acre-feet			
		Reservoir		Regulated Discharge Ac.Ft.	Evap. Acre-Feet	Inflow to Res.		Unregulated Discharge	
Year	Date	Storage Ac. Ft.	Alk. ppm.			Acre-Feet	Alk. ppm.	Ac. Ft.	Alk. ppm.
1916	June 1	10000	200	9600	3500	200100	123	197100	124
	July 1	50000	124	9920	4080	39780	148	25810	143
	Aug. 1	50000	143	3200	1130	7370	146	2940	149
	Aug. 16	50000	149	6720	2380	2320	187		
	Sept. 1	43220	159	9600	2430	4940	200		
	Oct. 1	34110	178	3100	1600	4180	187		
	Nov. 1	33590	185	3000	1060	3840	200		
	Dec. 1	34170	192	1550	670	1140	209		
1917	Jan. 1	33090	196	1550	840	1790	211		
	Feb. 1	32490	201	1400	870	1080	200		
	March 1	32100	209	3100	1650	1410	209		
	April 1	29760	220	3000	1550	6150	153		
	May 1	29060	216	3100	2090	2310	200		
	June 1	29180	230	9600	2500	452	200		
	July 1	17432	264	6080	1400	114	194		
	July 20	10068	301	0	750	70	194		
	Aug. 1	9386	324	0	770	900	211		
	Aug. 15	9516	348	8440	1510	48170	132	736	175
	Sept. 1	30000	178	3100	2740	29390	140	23550	167
	Oct. 1	50000	167						
1918	June 1	10000	200	9600	2580	57960	145	5780	162
	July 1	50000	162	7040	2870	16360	144	6450	165
	July 23	50000	165	2880	1180	920	197		
	Aug. 1	46860	170	9920	3330	8420	178		
	Sept. 1	39030	186	9600	2260	1390	211		
	Oct. 1	28760	203	3100	1330	875	194		
	Nov. 1	24655	214	3000	930	6605	167		
	Dec. 1	27930	210	1550	600	3540	171		
1920	Jan. 1	28720	209	1550	770	2040	211		
	Feb. 1	28440	215	1450	900	1390	209		
	March 1	27490	221	3100	1520	1320	209		
	April 1	24170	235	3000	1660	1310	209		
	May 1	20820	252	3100	1810	5310	178		
	June 1	21220	255	9600	2300	6390	153		
	July 1	17710	241	2880	670	340	211		
	July 10	14500	251	7040	1790	18410	144		
	Aug. 1	24090	219	9920	2670	18830	149		
	Sept. 1	30310	195	9600	2730	78830	122	43810	142
	Oct. 1	50000	142						
1922	April 1	10000	200	3000	1710	43726	134		
	May 1	49020	152	3100	2080	29268	140	23114	152
	June 1	50000	152	9600	3370	8250	167		
	July 1	43280	166	9920	3630	9650	158		
	Aug. 1	36380	179	9920	3120	6460	167		
	Sept. 1	32800	193	9600	2100	6250	167		
	Oct. 1	27350	202	3100	1380	1840	211		
	Nov. 1	24710	214	3000	900	3710	171		
	Dec. 1	24520	216	1550	550	938	209		

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Year	Date	Reservoir Storage Ac. Ft.	Reservoir Alk. ppm.	Regulated Disch. c Ft.	Evap. Acre-Feet	Inflow to Res. Acre-Feet	Inflow to Res. Alk. ppm.	Unregulated Discharge Ac. Ft.	Unregulated Discharge Alk. ppm.
1933	Jan. 1	23325	220	1580	690	321	194		
	Feb. 1	21406	228	1400	800	1140	209		
	March 1	20306	236	3100	1380	1840	211		
	April 1	17726	250	2800	1250	1660	211		
	Apr. 29	15835	256	200	100	1090	169		
	May 1	16126	259	3100	2080	93390	122	84136	148
	June 1	50000	148						
1931	April 1	10000	300	3000	1430	31000	140		
	May 1	38880	162	3100	2470	19980	149	990	165
	June 1	50000	165	7360	2600	16770	144	6810	167
	June 24	50000	167	2340	800	1360	187		
	July 1	48220	170	9920	3800	5280	179		
	Aug. 1	39780	188	9820	3040	428	194		
	Sept. 1	27342	209	9800	1840	154	198		
	Oct. 1	15956	233	8100	1040	79	194		
	Nov. 1	11595	252	1400	300	0			
	Nov. 15	10105	260	1600	380	5520	179		
	Dec. 1	13655	242	1550	480	2980	187		
1932	Jan. 1	14885	238	1550	630	6980	187		
	Feb. 1	19605	221	1400	810	7540	153		
	March 1	24925	208	3100	1530	8480	153		
	April 1	28785	204	3000	1650	9640	163		
	May 1	33575	200	9100	2300	14820	149		
	June 1	42995	192	9600	3370	64590	122	44615	151
	July 1	50000	151	8720	2740	14630	144	5170	187
	July 22	50000	187	3200	1300	310	209		
	Aug. 1	45810	162	9920	3340	7440	167		
	Sept. 1	39990	176	9600	2260	800	134		
	Oct. 1	29430	190	3100	1390	1200	209		
	Nov. 1	25150	202	3000	980	286	194		
	Dec. 1	21856	210	1580	570	2450	200		
1933	Jan. 1	21886	214	1550	670	817	200		
	Feb. 1	20483	230	1400	770	761	200		
	March 1	19074	228	3100	1320	1670	211		
	April 1	16324	248	2300	1020	740	209		
	April 24	13744	261	700	310	3620	148		
	May 1	16354	241	1800	1180	32070	128		
	May 19	45444	167	1300	1060	1320	187		
	June 1	44404	173	9800	3080	472	200		
	July 1	32196	190	9920	2050	2520	200		
	Aug. 1	21746	5.8	4500	1150	2870	167		
	Aug. 16	18666	226	5120	1440	29350	128		
	Sept. 1	41456	144	2240	580	20240	122	9876	148
	Sept. 8	50000	148	7360	2420	4190	187		
	Oct. 1	44320	158	3100	1770	4010	187		
	Nov. 1	43460	167	3000	1190	5560	179		
	Dec. 1	44830	173	1550	770	2120	211		
1934	Jan. 1	44830	178	1550	970	4400	187		
	Feb. 1	48510	185	1400	1160	3990	187		
	March 1	47940	190	3100	2040	5830	179		
	April 1	45430	197	1100	850	35060	122	31540	187
	Apr. 12	50000	187	1900	1470	700	200		
	May 1	47390	173	3100	3830	992	200		
	June 1	42502	184	9600	3300	13210	148		
	July 1	42902	187	9920	3480	95	194		
	Aug. 1	23597	209	9920	2600	1130	209		
	Sept. 1	18207	239	2880	800	1910	187		
	Sept.10	16737	259	5440	950	7200	148		

34 E

Year	Date	Reservoir		Regulated Disch. Ac.Ft.	Evap. Acre-Feet	Inflow to Res.		Unregulated Discharge	
		Storage Ac. Ft.	Alk. ppm.			Acre-Feet	Alk. ppm	Ac. Ft.	Alk. ppm.
1936	Sept.27	17547	241	1280	220	2840	148		
	Oct. 1	19897	237	1700	640	30	300		
	Oct. 15	18587	245	1400	560	3990	144		
	Nov. 1	23517	218	3000	910	4980	200		
	Dec. 1	24567	223	1550	580	2080	211		
1938	Jan. 1	24817	228	1550	730	1910	200		
	Feb. 1	24147	233	1400	850	2530	187		
	March 1	24527	236	3100	1490	4150	187		
	April 1	24117	242	3000	1610	519	200		
	May 1	20026	260	1300	750	45	200		
	May 16	18021	272	1800	1560	177055	122	141716	137
	June 1	50000	137	9600	3580	28440	140	15340	146
	July 1	50000	146	3580	1170	9240	128	5190	146
	Aug. 1	42110	155	9920	3120	1160	201		
	Sept. 1	30230	176	9600	2180	16840	149		
	Oct. 1	24690	175	3100	1460	383	194		
	Nov. 1	30403	184	3000	980	250	196		
	Dec. 1	26783	191	1550	600	519	200		
1938	Jan. 1	25152	198	1550	750	1300	209		
	Feb. 1	24152	203	1450	850	1170	209		
	March 1	23022	211	3100	1400	870	200		
	April 1	19292	228	3000	1430	101	194		
	May 1	15063	247	400	230	20	200		
	May 8	14483	250	2700	2260	85200	122	44823	146
	June 1	50000	146	6080	2303	130460	122	117080	130
	June 20	50000	130	3520	1240	2500	167		
	July 1	47740	136	9920	3800	2430	200		
	Aug. 1	38480	154	9920	2780	151	194		
	Sept. 1	23901	172	1600	380	4	200		
	Sept. 6	21928	176	9000	1850	32788	146		
	Oct. 1	44961	157	3100	1770	3810	179		
	Nov. 1	45631	175	3000	1170	760	200		
	Dec. 1	42191	181	1550	750	1560	211		
1937	Jan. 1	41451	190	2950	3020	4720	195		
	March 1	4[illegible]	200	3100	1820	3850	197		
	April 1	39531	208	3000	2050	1810	211		
	May 1	35991	220	3100	2420	14450	148		
	June 1	4[illegible]921	218	9600	3500	167410	122	148231	140
	July 1	[illegible]700	140						

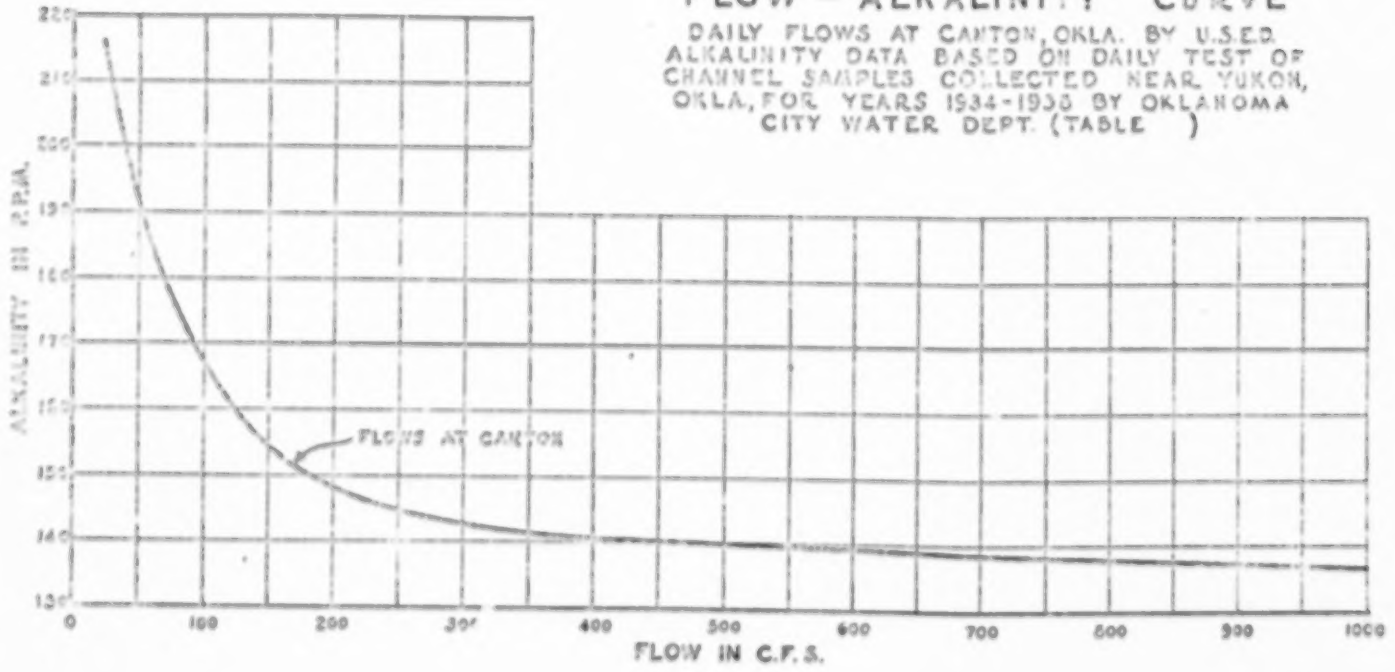
34.F

FIGURE NO. 6

NORTH CANADIAN RIVER

FLOW - ALKALINITY CURVE

DAILY FLOWS AT CANTON, OKLA. BY U.S.E.D. ALKALINITY DATA BASED ON DAILY TEST OF CHANNEL SAMPLES COLLECTED NEAR YUKON, OKLA. FOR YEARS 1934-1938 BY OKLAHOMA CITY WATER DEPT. (TABLE)



$$V_2 = (V_1 + F) - (D + E)$$

$$A_2 = \frac{(A_1 V_1) + FA_3) - (DA_1)}{V_2}$$

where:

V_1 = Initial volume of reservoir (acre-ft.) at any time.
V_2 = Volume of reservoir (acre-ft.) after "t" days.
D = Discharge from reservoir (acre-ft.) for "t" days.
E = Evaporation (acre-ft.) in reservoir for "t" days.
F = Inflow to reservoir (acre-ft.) for "t" days.

A_1 = Initial alkalinity (ppm) of reservoir at any time.
A_2 = New alkalinity (ppm) reservoir after "t" days.
A_3 = Alkalinity (weighted in ppm) of inflow (F)

Application of Equations:

(1) The computed fluctuations in conservation storage and alkalinity in the reservoir are tabulated by months for the selected flow periods, however individual computations were made by days, or groups of days, depending upon rates of inflow (F).

(2) Alkalinity of discharges was taken as the initial alkalinity of reservoir water (A_1).

(3) Monthly adjustments were made for diffusion of inflow and reservoir waters.

(4) No data were available on seepage losses in the reservoir.

The critical flow periods selected for computing, hypothetically, the operation of Canton Reservoir, had it been in operation for pollution abatement, are as follows:

June 1, 1916 to October 1, 1917
June 1, 1919 to October 1, 1920
April 1, 1922 to June 1, 1923
April 1, 1931 to July 1, 1937

Results of these computations are shown in Table 15. From these data the difficult periods of selectivity would have occurred from July, 1932 to May, 1935. During that

interval spills of 8900 acre-feed (alkalinity 148) in September 1933 and 31,500 acre-feet (alkalinity 167) in April, 1934, represented the only uncontrolled flow at Canton. For a portion of this period, considering no inflow below Canton, selection of water exceeding 150 p.p.m. alkalinity would have been necessary.

The run-off at Canton for the years 1933 and 1934 totaled slightly over 205,000 acre-feet, while the run-off at Oklahoma City for the same period totaled 375,309 acre-feet. The drainage area between Canton and Oklahoma City contributed in September, 1933, about 41,000 acre-feet of run-off with a computed average alkalinity of 135 p.p.m. Run-off from the same area in September 1934 totaled about 49,000 acre-feet at a computed average alkalinity of 135 p.p.m. Diversion of these flows would have supplemented deficiencies from Canton.

The bottle-neck section of the watershed, between Canton and Oklahoma City, has a drainage area of 770 square miles. The comparison in annual run-off at the two points for the years 1914-1938 are shown in Table 16.

Table 16 - Comparison in Annual Run-off North Canadian River, in acre-feet at Canton and Oklahoma City for the years 1914 - 1938. (Computed from hydrometric data of the U. S. Engineer Office, Tulsa, Oklahoma.)

Year	Ann. Run-off (AF)		Excess	Year	Ann. Run-off (AF)		Excess
	Canton	Oklahoma City	Okla. City		Canton	Oklahoma City	Okla. City
1914	150208	185885	35677	1927	152814	282621	129807
1915	561162	680559	119397	1928	183810	190221	6411
1916	277564	329398	51834	1929	93400	193113	99713
1917	105806	168531	62725	1930	121330	241193	119803
1918	153090	183352	30262	1931	110545	116186	5641
1919	148070	197017	48947	1932	138636	215960	77324
1920	249150	393240	144090	1933	112240	203235	90995
1921	172730	244952	72222	1934	93027	172074	79047
1922	149129	219647	70518	1935	244501	239096	--
1923	796861	1081030	284169	1936	254922	257605	2683
1924	108540	169616	61076	1937	267862	194632	--
1925	93930	142431	48501	1938	220899	357722	336823
1926	165450	128405	--	Ave.	304989	279509	74,480*

* Deficit flows for 1926, 1935 and 1937 included.

From these data the annual run-off at Oklahoma City averages about 74,000 acre-feet more than that at Canton.

Monthly discharges, for the years 1914 1938, show that for 12 of the 25 years, flows at Oklahoma City for some months, exceeded similar flows at Canton by 500 c.f.s. or more. Run-off from this area is obviously a factor in the analysis of the Oklahoma City water supply problem.

Regarding the practice of selectivity for off-channel storage at Oklahoma City, the following conclusions appear warranted:

(1) With no upstream storage retention reservoirs, Oklahoma City could secure sufficient water with an average alkalinity range of 120 to 140 p.p.m.

(2) With the proposed Canton reservoir operated with 40,000 acre-feet storage for stream regulation, Oklahoma City could secure sufficient water with an average alkalinity range of 130 to 150 p.p.m. On a basis of averages, removal of the 15 p.p.m. additional hardness (corresponds to 10 p.p.m. alkalinity), as calcium bicarbonate, would add about 50 cents per million gallons to treatment cost. (Lime $8.40 per ton - 80% C_aO). Present treatment methods at Oklahoma City do not include removal of non-carbonate hardness.

(3) Retention of flood waters at the Canton reservoir, with subsequent controlled release, would aid diversion practices at Oklahoma City.

Other Effects of Conservation Storage on Water Quality

Bacteria: Conservation storage in the Canton Reservoir would have no detrimental effect on the bacterial quality of river water reaching Oklahoma City.

Biological: In general, when reservoirs are constructed for water conservation, consideration should be given to the probable development of algae, and the effect of such development on the taste and odor characteristics of the water.

Available data is insufficient to forecast the effect of conservation storage at Canton on biological quality of river water reaching Oklahoma City. However, regardless of storage at Canton for pollution abatement, a 10,000 acre-feet permanent pool is to be provided.

Irrespective of upstream storage, local water treatment problems resulting from biological activity, would develop subsequent to diversion to off-channel storage at Oklahoma City. If conservation storage at Canton is limited to 40,000 acre-feet it is doubtful if dilutions from this storage, during periods of high flow, would exert much influence on the biological development in the off-channel reservoir at Oklahoma City.

Deep Fork River

Deep Fork River, the principal tributary of the North Canadian River, has its source in central Oklahoma, near Oklahoma City. The stream, approximately 220 miles in length, flows easterly to Okmulgee, Oklahoma, thence southeasterly to its confluence with the North Canadian River at about mile 15. The 2,540 square mile drainage area is all in Oklahoma.

In the Deep Fork basin public water systems serve 54,600 population residing in 14 communities. Public sewerage systems are available to 46,600 persons in 10 communities. As a source of water supply five communities (combined population about 28,000) use surface water from streams tributary to Deep Fork River. The main stem is not used as a source of supply. Of the 10 sewerage systems seven include secondary treatment plants and two primary.

Brine waste reaches the Deep Fork River from extensive oil field developments in the basin. No accurate production figures are available for the area.

Stream flow in the Deep Fork River is very irregular and long periods of low flow are common. Annual rainfall averages about 35 inches.

Although no detailed investigation was made of the Deep Fork basin, available factual data indicate that pollution, especially that due to brine waste, reaches detrimental proportions during periods of low flow.

Stream regulation by conservation storage, together with effective treatment (equivalent to a minimum reduction of 85% first stage B.O.D.) of municipal waste below such regulation, would abate organic pollution. It is doubtful if sufficient water could be provided for proper dilution of brine waste.

Water uses are similar to those of the North Canadian River below Oklahoma City.

No definite water development program has been announced for the Deep Fork River.

Appendix A

Hydrometric Data (Stream Flows-Sec. One)

Hydrometric data used in the report were secured from the U. S. Engineer Office at Tulsa, Oklahoma. These data included tabulated monthly flows for the North Canadian River, for 20 or more years, at Guymon, Beaver, Canton, and Oklahoma City. Tabulated monthly flows for Wolf Creek at Fort Supply, Oklahoma, for the period 1908-1939, were also available. The Canton data were included with daily flow estimates for the period 1914-1938.

The monthly flow data for Guymon, Beaver, and Oklahoma City are reproduced on the following pages. Because of volume, the daily flow data for Canton are omitted. However, copies of these data are available at the Office of Stream Sanitation, U. S. Public Health Service, Cincinnati, Ohio, and at the U. S. Engineer Office, Tulsa, Oklahoma.

In transmitting requested stream flow data, the District Engineer, U. S. Engineer Office, Tulsa, Oklahoma, stated: "... the records are the best obtainable and are reasonably representative of discharges at each site...."

Reproduced from best available copy.

NORTH CANADIAN RIVER - GUYMON, OKLAHOMA
Estimated Monthly Flows in Cubic Feet per Second

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1918	2.37	40.8	215	117	63.4	14.9	78.5	68.7	243	86.5	33.0	6.77	80.9
1920	5.40	0.36	0.16	4.48	53.5	57.5	12.9	38.2	112	64.0	4.92	4.72	29.8
1921	14.60	16.6	1.47	14.7	121	222	666	48.0	9.64	0.66	0.95	0.91	88.9
1922	0.15	19.4	30.2	16.1	45.6	53.2	38.4	42.4	13.2	0	4.47	0.03	21.9
1923	4.40	16.5	8.33	28.6	53.6	314	61.2	139	366	864	30.6	43.0	120.6
1924	0.60	0.52	45.0	26.9	23.8	4.63	27.6	70.5	30.7	6.37	0	0	20.5
1925	1.08	8.98	0.73	5.10	26.7	54.2	937	154	312	17.7	10.4	0.51	78.2
1926	0.78	1.07	45.6	102	176	160	39.3	66.5	89.8	4.53	0.33	4.94	53.5
1927	0.97	1.22	6.92	27.4	1.55	76.5	469	412	70.6	0.60	0.78	0.89	91.9
1928	3.72	5.25	24.9	43.6	519	219	62.5	36.7	14.9	66.0	111	8.06	94.9
1929	1.65	1.14	26.4	0.70	25.1	27.5	145	250	79.5	13.3	49.2	0.79	51.3
1930	1.66	3.07	5.56	10.3	40.4	66.4	150	10.0	198	569	23.5	1.16	59.5
1931	0.87	5.43	26.2	53.6	56.4	38.3	80.2	140	48.5	13.0	0.33	4.73	35.0
1932	8.94	0.64	17.5	79.7	13.4	220	0.26	9.56	30.7	4.24	0	4.24	32.0
1933	0.10	0.07	0	4.36	62.2	17.7	17.0	263	31.0	4.31	21.9	6.26	36.2
1934	0.08	23.9	0.16	0	12.8	22.0	12.8	12.8	39.6	21.3	0	0	12.0
1935	4.24	0	4.24	0	61.9	21.9	21.2	12.7	26.8	8.50	13.2	0	16.8
1936	4.39	6.16	0	0	138	26.3	25.5	4.24	46.0	0	0	0	20.5
1937	0	0	8.50	4.38	118	251	13.1	4.28	42.8	12.7	0	4.27	37.9
1938	0.50	10.4	4.82	18.2	26.5	186	132	4.62	156	77.2	0.75	4.98	52.2
1939	11.20	5.36	24.1	61.6	3.39	160	58.3	30.6					
Total	65.80	150.49	493.91	820.84	2012.84	2200.08	3890.78	1812.80	1915.44	1333.91	313.33	96.89	
Mean	3.16	7.19	28.51	29.56	95.85	104.76	114.13	86.32	95.77	66.70	15.67	4.62	
												Total	1062.8
												Mean	58.14

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NORTH CANADIAN RIVER - BEAVER, OKLAHOMA
Estimated Monthly Flows in Cubic Feet per Second

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1919	8.57	136	405	275	304	180	159	163	462	154	88.5	6.6	203.1
1920	24.1	4.70	8.14	36.9	234	188	126	136	405	57.8	169	50.0	121.1
1921	72.6	54.4	6.69	83.4	339	858	1005	154	47.6	2.86	3.53	3.56	220.2
1922	12.6	73.0	202	120	91.5	234	188	99.8	98.8	0	45.2	0.10	84.7
1923	6.76	45.2	70.0	172	276	1326	120	899	973	1528	126	101	413.4
1924	3.68	17.3	186	55.7	102	78.7	206	163	51.8	50.0	0.32	0.16	77.5
1925	4.71	18.9	2.88	48.8	116	153	726	563	903	39.2	68.8	3.72	225.0
1926	7.42	23.0	181	252	645	565	127	204	222	27.8	4.80	49.5	193.2
1927	5.96	6.82	47.2	120	7.20	264	1369	1262	249	16.5	4.27	3.68	294.5
1928	4.35	56.2	113	116	1530	795	246	228	48.5	238	364	33.7	315.7
1929	8.57	23.6	131	5.56	157	143	441	352	189	41.0	231	6.16	145.1
1930	5.96	6.84	3.74	68.2	124	492	390	65.7	236	935	46.4	8.91	207.2
1931	4.56	7.32	117	244	330	269	202	268	117	50.6	41.4	42.3	145.2
1932	29.0	11.4	101	349	77.4	837	39.1	50.4	141	24.8	0.72	46.2	140.9
1933	1.31	1.32	0	28.3	285	39.6	68.3	1098	27.2	25.7	167	13.8	148.0
1934	1.58	70.6	0.24	0	80.8	269	68.3	99.4	205	74.6	0.15	0.13	72.0
1935	6.67	0.25	37.1	0	478	180	37.1	112	102	37.1	64.2	0.32	88.7
1936	29.6	1.18	0.31	0	930	322	132	0.40	231	0	0.03	0.32	137.2
1937	1.31	15.8	37.8	13.5	386	720	32.1	31.6	192	24.9	0.08	0.31	120.9
1938	2.84	60.3	40.7	132	124	218	264	51.7	910	252	17.2	8.60	172.5
1939	42.8	12.5	66.7	259	369	855	493						
Total	275.11	645.53	1761.60	2569.86	6876.90	9015.30	6389.90	5301.40	5889.40	3567.56	1457.60	370.46	3526.4
Mean	13.10	30.74	83.89	122.35	327.47	429.30	304.28	265.07	294.47	178.38	72.88	18.52	176.32

NORTH CANADIAN RIVER - OKLAHOMA CITY, OKLAHOMA
Estimated Monthly Flows in Cubic Feet per Second

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1914	194	80.4	29.4	48.3	1464	398	292	105	127	172	46.4	124	257.1
1915	125	148	599	1744	1631	2045	2168	1362	1432	185	13.1	32.6	841.3
1916	64.6	16.4	85.6	148	73.5	3497	1010	244	129	106	69.1	60.5	455.6
1917	94.9	55.7	26.4	214	39.0	7.96	4.66	1345	771	199	53.4	54.7	232.1
1918	176	44.2	40.8	130	551	489	252	35.7	455	369	122	382	253.6
1919	158	167	191	281	476	1012	438	137	41.7	9.35	179	182	272.5
1920	108	37.9	33.5	34.3	89.9	147	476	479	1988	2531	276	304	548.9
1921	320	167	95.8	216	31.2	1217	665	607	570	70.9	26.5	80.4	338.8
1922	134	142	648	1146	45.5	109	244	164	164	46.9	97.2	49.4	303.8
1923	17.0	34.5	46.9	72.3	1860	3498	128	72.8	1597	10160	357	247.0	1498.2
1924	71.1	53.9	384	234	151	117	59.5	236	527	49.5	229	218	234.6
1925	84.0	44.5	105	148	96.6	227	97.9	455	574	245	198	95.0	197.0
1926	91.5	148	155	237	136	146	92.5	37.8	166	440	113	278	177.6
1927	269	214	260	1241	202	271	16.3	1660	230	177	65.0	87.4	390.9
1928	137	222	181	269	946	593	182	19.8	0	0	878	338	263.1
1929	299	233	506	599	850	298	161	0	3.73	0	122	120	267.1
1930	62.1	312	137	3.70	1526	572	173	0	62.6	457	203	187	332.6
1931	142	126	225	553	456	239	27.7	7.19	0	0	71.5	89.1	160.7
1932	217	152	110	99.2	137	1852	931	154	41.6	0	26.4	74.2	298.7
1933	100	63.1	166	73.2	991	89.5	4.66	306	1108	140	169	150	281.1
1934	144	89.3	107	536	83.9	471	1.88	134	1013	186	51.5	62.4	238.0
1935	0	0	89.7	22.7	2171	777	317	29.4	488	31.4	.63	7.06	330.7
1936	12.8	9.83	9.61	7.70	963	2376	84.7	5.94	473	217	110	31.9	356.3
1937	86.0	113	120	46.8	47.2	1636	83.0	134	620	145	124	128	269.2
1938	128	70.1	122	557	1442	948	139	69.3	934	12.5	407	4356	771.4
1939	39.1	30.9	42.9	595	209	621	770	74.2	-	-	-	-	-
Total	3880.00	2746.43	4946.51	9357.99	16386.60	23731.40	9254.31	7773.88	13523.03	15909.45	3385.63	7698.66	9664.9
Mean	125.00	105.55	174.87	389.92	630.34	912.78	355.93	298.97	540.95	636.38	135.43	307.83	386.60

Appendix B

Oxidation & Reaeration (Question "A", Section Two)

Under Question "A", Section Two, reference was made to studies by Streeter & Phelps*, of oxidation and reaeration in the Ohio River, from which studies mathematical equations were developed expressing the relations of these phenomena. These equations were developed as follows:

The combined influence of deoxygenation and reaeration on progressive changes in D.O. content of a polluted stream is very characteristic, readily observable in a stream, unless disturbed unduly by intermediate inflow. Its general form is that of an inverted bow, with the extended limb reversing its curvature in a downstream direction and approaching an asymptote represented by complete oxygen saturation. It is often termed the "oxygen sag" curve because of its tendency to sag in the "inverted bow" section, with the minimum point marking the central zone of oxygen depression in the stream resulting from the initial stage of rapid deoxygenation immediately below the source of pollution.

On the basis of two assumptions: (1) that the rate of deoxygenation is directly proportional at any time to the unsatisfied oxygen demand of the stream at that time, and (2) that the rate of atmospheric reaeration (the only form considered) is directly proportional at any time to the oxygen saturation deficiency existing in the stream at that time. Both assumptions are in accord with well-established observational fact.

A simple first-order linear differential equation, on the basis of these assumptions, was set up as follows:

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* *H. W. Streeter and E. B. Phelps. "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Bull. 146, U. S. Public Health Service (1925).*

$$\frac{dD}{dt} = K_1 L_t - K_2 D_t$$

D_t = D.O. saturation deficiency at any time (t)

L_t = remaining unsatisfied O.D. at the same time.

K_1 = a constant defining specific rate of deoxygenation.

K_2 = similar constant defining rate of reaeration.

In the integrated form the equation gives the value of (D_t) at any time.

$$D_t = \frac{K_1 L_a}{K_2 - K_1} \left(e^{-K_1 t} - e^{-K_2 t}\right) + D_a \cdot e^{-K_2 t}$$

L_a = Stream B.O.D. at initial reference point.

D_a = D.O. saturation deficiency at same point.

e = base Naperian logarithm system (2.7183).

When common base (10) is substituted, the equation becomes:

$$D_t = \frac{k_1 L_a}{k_2 - k_1} \left(10^{-k_1 t} - 10^{-k_2 t}\right) + D_a \cdot \left(10^{-k_2 t}\right)$$

where $k_1 = 0.434\ K_1$ and $k_2 = 0.434\ K_2$

Both equations (1) and (2) will give identical results if the proper constant ratio of (K_1) and (K_2) to (k_1) and (k_2) is consistently observed.

The lowest point of the "oxygen sag" curve may be derived by differentiating equation (1) with respect to time, and placing the resulting expression equal to zero, which gives the following equation:

$$e^{(K_2 - K_1)t} = \frac{K_2}{K_1}\left[1 - \frac{D_a (K_2 - K_1)}{K_1 L_a}\right]$$

If this expression be transferred to terms of the constants (k_1) and (k_2), it may be written:

$$10^{(k_2-k_1)t} = \frac{k_2}{k_1}\left[1 - \frac{D_a(k_2-k_1)}{k_1 L_a}\right]$$

$$t = \frac{\log\left\{\frac{k_2}{k_1}\left[1 - \frac{D_a(k_2-k_1)}{k_1 L_a}\right]\right\}}{(k_2-k_1)}$$

Equation (3) gives the time (t) corresponding to the minimum point of the "oxygen sag" curve, using common logarithms. By calculating this and substituting it into (2), the ordinate (D_t) of the curve at the minimum point can be readily computed. This minimum point marks the approximate center of the critical zone of oxygen depletion in a stream below a point of major source of pollution.

By trial procedure dilution requirements were computed for seasonal temperatures, using the minimum dissolved oxygen residual of 3 p.p.m. at the critical point of oxygen depression.